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NOTICES.

The Institution as a body is not responsible for the statements or opinions expressed in any of its publications.

Copyright. The entire contents of the Journal are covered by general copyright, and official permission is necessary for reprinting long abstracts; but editors may use not more than three pages of any paper, provided that credit is given as reproduced from the Journal of The Institution of Petroleum Technologists or advance-proofs thereof.

Issue of Journal. The Journal appears in four parts per sessional volume, viz. in January, April, July and October. A brochure describing the origin, progress and purposes of the Institution, and comprising also the Memorandum and Articles of Association, the By-Laws and Regulations of the Institution, the Library Catalogue to date (with subject index), and the List of Members, was published in September, 1915, to be followed annually by revisions of the Library Catalogue and List of Members.

Members of all classes are entitled to receive these publications free: for additional copies of the Journal they will be charged at the price of Seven shillings and sixpence per part, and of the brochures at the prices stated on the wrappers, varying in proportion to bulk.

Changes of Address. It is particularly requested that members notify the Secretary immediately of any change of address; and members are also requested to advise the Parcel-Post Department as well as the Letter Office, of any temporary change of address, as, unless this is done, parcel-post packets will not be re-addressed; but will be returned to the offices of the Institution in London, thus incurring further expense for postage.

To Authors of Papers. Papers should be written in the third person, and the copy should be carefully corrected by the author before it is presented.

All drawings, diagrams or other illustrations should be sent in a fit state for direct photographic reproduction.

All quotations, technical terms, and localisms should be indicated by means of inverted commas.

Foreign weights, measures, and costs should be given whenever possible; and also their English equivalents.

It is suggested that authors append as complete a bibliography of the subject treated as may be possible.

All papers and notes submitted to the Institution are supposed to be original communications unless distinctly stated to be otherwise, in which case the exact reference to the previous publication should be given.

Communications upon papers read at meetings, notices of personal movements, or other matter for which publication is desired in the next issue of the Journal, should be in the hands of the Editor on or before the last day of December, March, June or September as the case may be. Subsequent delivery may be too late for insertion.

The Council desire to draw the attention of authors to the serious increase in the cost of production. Papers, both for the Journal and for communication to the Institution, should be as concise and condensed as possible.

Special Meetings. Special meetings are arranged for November and February in addition to the ordinary scientific meetings. On November 23rd there will be a series of short Chemical papers, and it is hoped that a discussion on the "Origin of Petroleum" will be held in February. These meetings are more specifically intended for those members who hitherto have not contributed to the Institution's Journal or Proceedings.

Communications. The Council invite members to submit papers for the forthcoming session. Communications to the Institution will, subject to the approval of the Publication Committee, be published in the Journal.

Appointments Register. A Register will be kept at the Offices of the Institution for the convenience of firms requiring the services of members and for members requiring appointments, but on the distinct understanding that the Institution accepts no responsibility and gives no guarantee.

Library. The Institution's Library is in course of reorganisation in the new premises at No. 5, John Street, Adelphi, and may be consulted between 11 and 4 daily. Extensive additions are being made to the current and standard literature on Petroleum.

The attention of members is drawn to the new supplement of the Journal which deals with current Petroleum Literature. To make this section of the maximum usefulness it is necessary that there should be full co-operation between chemists, engineers and geologists,

and that matter which has inadvertently escaped notice shall be immediately sent in to the Editors. The Institution is indebted to Mr. Andrew Campbell for the compilation of the bibliography.

Advertisements in the Journal. A limited number of Advertisements of firms interested in the Petroleum Industry may be inserted in the Journal. Application for terms, etc., should be made to the Secretary.

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PERSONAL NOTES OF MEMBERS AND SPECIAL NOTICES.

It is suggested that Members of the Institution send information regarding their movements to the Secretary for insertion under this heading.

Prof. T. TAKAKUWA, of the Kiriu College, Japan, is on a visit to this country for the purpose of obtaining information and literature dealing with petroleum technology. Before his duties at the College he was Chief Refining Engineer to the Hoden Oil Company. He has not only applied for Membership of the Institution, but has purchased a complete issue of our Journals from 1 to 24, which he intends to use in the University for training Students in the profession.

The members will note with pleasure that the Institution has been giving practical advice to Students choosing the career of Petroleum Technology, so that they may be trained in the more

thorough and up-to-date methods, which, "like the hands of time," keep advancing onward.

The Council, on behalf of the members of the Institution, desire, through the Journal, to thank Mr. ROBERT REDWOOD for presenting two very handsome models. One shows the primitive way of Petroleum Winning in the East, and the other, perfect in all its parts, of a Drilling Rig made in teak wood.

Mr. J. WILFRID BURFORD is home on leave from Lobitos.

Mr. ALEXANDER CLUBB returned from Bombay in September.

Prof. JOHN BRETLAND FARMER, D.Sc., M.A., F.R.S., Imperial College of Science and Technology, has been appointed by an Order of Council dated the 28th day of August, 1920, to be a member of the Advisory Council to the Committee of the Privy Council for Scientific and Industrial Research.

Mr. BASIL F. N. MACRORIE returned from British Guiana and Trinidad early in October.

Mr. F. W. MOON has been appointed Petroleum Research Geologist to the Egyptian Government.

Dr. F. MOLLWO PERKIN has had the honour of C.B.E. conferred upon him.

Mr. C. B. ROSENPLAENTER left for America in June.

Mr. ROBERT STIRLING has now returned to London from Curacao in time personally to reply to the criticisms made on his paper, which criticisms will be found in this issue.

Mr. WILLIAM SUTTON returned from India in July.

Mr. M. L. THOMAS left for Venezuela in September.

OBITUARY NOTICES.

BLUNDSTONE.—On the 22nd August at his residence, "Heathfield," Hampton Hill, Middlesex, after five years' illness, Edwin Richardson Blundstone, B.A. (Cantab.), F.C.S., Member of Council, of 79, York Street, Westminster, aged 68.

By the death of Mr. EDWIN R. BLUNDSTONE, B.A. (Cantab.), F.G.S., Science and Industry have lost another prominent member from their ranks. The deceased was very closely connected with the late Sir Boverton Redwood, and may be regarded as one of the pioneers of the Petroleum Industry. His duties carried him into Rumania, Egypt, Peru, the Dutch East Indies, Canada and different parts of America. He was appointed chief geologist to the Commission sent out by the

Government to report on the oilfields of Persia, and was a geologist and chemist of quite exceptional ability.

FISHER.—The Institution has to mourn the loss of Admiral-of-the-Fleet, Right Hon. Lord Fisher of Kilverstone, G.C.B., O.M., G.C.V.O., who was one of the Institution's Hon. Members. Lord Fisher's reputation was national and his fame was world wide.

The Institution will always think of him as a man who took the greatest interest in all petroleum matters, and who by his continual advocacy and personal stimulus persistently supported the use of oil fuel in the Navy.

HAMILTON.—On the 18th July, 1920 (Sunday), at his residence, "The Hollies," Newlands, Glasgow.

Mr. James Hamilton joined the staff of the original Burma Oil Company in 1886, and served with a loyalty, devotion and ability of the first order. For the past 27 years he was in daily touch with the affairs of this Company, and he only resigned the managership owing to failing health at the end of last year. He was a Founder Member of The Institution of Petroleum Technologists.

HAWKINS.—We regret to announce the death of our member, the late Mr. A. B. Hawkins.

Mr. Hawkins joined the service of the Assam Oil Company, Limited, as General Manager in 1904, and immediately devoted himself to the study of practical refining methods, which he successfully instituted in the Company's refinery at Digboi. He spent in all about sixteen years as a Petroleum Producer and Refiner.

Mr. Hawkins' abilities were recognized by the Government, and he was appointed to the Assam Legislative Council.

Mr. Hawkins had been suffering from ill-health for several years past, and was to have retired finally from the Company's service at the end of the present year. He was on his way home, *via* New Zealand and Panama, when he died at sea on the 12th of August last.

ROGERS.—On the 17th August at Loughton, Essex, Willie Rogers, late of Negheriting, Assam, aged 61.

For several years Mr. Rogers served the Institution loyally and faithfully, firstly as Hon. Assistant Secretary and latterly as Secretary. His kindly presence and unfailing courtesy endeared him to all who came into contact with him and his loss will be severely felt.

REVIEWS.

"Oil-Finding." By E. H. Cunningham Craig, B.A., F.R.S.E., F.G.S. Pp. 324, 13 plates, London, 1920. *Edward Arnold*, 41/43, Maddox Street, London, W. Price 16s.

Petroleum Technologists will welcome the enlarged second edition of "Oil-Finding," by E. H. Cunningham Craig, B.A., F.R.S.E., F.G.S. The book is admittedly a clever exposé of Petroleum Technology commencing with the origin of petroleum and ending with general advice concerning field work and indoor work. The origin of petroleum is dealt with under Natural Laws and not from chemical theorising, and the able style of description and natural argument used by the author will meet with many adherents.

After dealing with the process of formation, the storage of petroleum and lateral variation, a clearly worked out case for "Geological Structures" is elaborated. One very important part of this chapter is the section relating to "Faults" or "Fissures." There is no part in Geology that tries the knowledge of man more than when he meets with results of earth-movements which have not only folded and corrugated the rocks, but have fractured them in all directions. The author distinguishes between "faulted" ground, which is well-nigh useless for the drill, and faults which may more or less help to preserve the petroleum from continuing its migration tendencies in what might have otherwise been more or less pervious strata.

The book is copiously illustrated with actual photographs and diagrams; the latter as restorations help to illuminate and "ease off" the technical side of a book which will be found invaluable by all engaged in the working of petroleum.

"Popular Oil Geology." By Victor Ziegler, Consulting Geologist, formerly Professor Colorado School of Mines. Pp. 171, New York (*John Wesley & Sons*), and London (*Chapman & Hall, Ltd.*). 1920. Price 15s. net.

This most interesting book has entered into its Second Edition, considerably enlarged, profusely illustrated with photographs and diagrams. Some of the latter are remarkable restorations which only a practical man could produce. As the author admits, the book is a compilation of most valuable matter drawn from leading Geologists and Chemists of unquestioned authority, and is admirably arranged in perfect sequence by a man of clear scientific penetration and practical geological experience. A Technologist in Petroleum

Science wanting a companion will find "Popular Oil Geology" by Ziegler a valuable friend. The rewritten parts, notably the chapter on Oil Shales, the Migration of Oil and Gas, and on the Anticlinal Theory, with much new material, add considerably to the value of the book.

"Geology of the Mid-Continent Oil-Fields." By Dr. T. O. Bosworth, D.Sc., M.A., F.G.S., formerly of H.M. Geological Survey of Great Britain. Pp. xii, 314. *Macmillan & Co.*, London. 1920.

We are glad to receive from one of our Members, Dr. T. O. Bosworth, an advance copy of his latest literary and technical production. Petroleum Technologists interested in Oil Geology of the Mid-Continent of the United States will find in this book a complete reference-in-section of the rocks of the districts comprised in the Mid-Continent, as follows: (*a*) 50 Oilfields in Kansas; (*b*) 75 Oilfields in Oklahoma; (*c*) 3 Gasfields in Arkansas; and (*d*) 18 Oilfields in North Texas, and which, from a "master-pen" of an author like Dr. Bosworth, puts a high value on the geological findings of the author. These are profusely illuminated by specially drawn diagrams and selected oil photographs. In the great oilfield region described it has been shown that the oil occurs in a pile of marine sediments, which still lie almost as they were deposited. No vulcanicity has affected this oil region, and the deposits are free from igneous intrusions. Saline domes, crystalline plugs, solfataric phenomena, or mysterious fissures are absent, and there are rather few faults. The book also deals with carbonaceous materials in the formation, advancing the theory that vegetable matter is a probable source of petroleum. A very important section deals with the relation between shore-lines and oilfields. His description of migration of the oil and gas, how the oil accumulates and the relation between gas pressure and depth, are valuable additions to Petroleum Science. There appears to be a persistency and consistency throughout the whole field, a field the greatest of the world's developed oil territories.

Forty-Sixth General Meeting.

This Meeting was held at the House of the Royal Society of Arts, John Street, Adelphi, W.C. 2, on Tuesday, 20th April, 1920, Sir Frederick W. Black, K.C.B. (President), occupying the Chair.

The Members of Council present were Messrs. H. Barringer, E. H. Cunningham Craig, Alexander Duckham, Dr. A. E. Dunstan, Mr. Arthur W. Eastlake, Dr. W. R. Ormandy, and Mr. Robert Redwood.

The President, at the opening of the meeting, announced that the final meeting of the session would be held on the third Tuesday in May, when a paper would be read by Mr. Robert Stirling. After that the majority of the members would be able to go to sleep, as far as the Institution was concerned, until October, but a certain number of the members of the Institution hoped to be very active during the summer season at the Exhibition which was being held at the Crystal Palace. It was well known that there was a big Oil Section at that Exhibition, in which all the Companies interested in oil, tools, and appliances were taking part, and the Institution was trying at the present time to obtain from the Crystal Palace authorities the use of a lecture room so that certain of its members might give four, six or even more popular lectures on the subject of petroleum. The lectures would be of a distinctly popular character, but also of an educative nature, in order to interest people in the subject, and he might perhaps say incidentally to help to advertise the Institution of Petroleum Technologists. In the present day as long as an article was good and sound he did not think there was any apology needed for advertisement. By means of a little judicious advertisement the Institution had already succeeded in getting several of the oil companies to help the Institution financially, and by that means it would be possible greatly to extend the activities of the Institution. (The President here referred to valuable help which Mr. Alexander Duckham, who was then entering the room, had given in this connection.) Plans were already being prepared for next year's meetings, and it was hoped that one feature of them would be that, in addition to the ordinary meetings of the usual character, there would be two special young men's evenings. The Council thought that at one meeting one of the student members should be asked to address the members, and at the other meeting the younger members in particular would be asked to put forward suggestions and even to say what they thought of their elders, and generally tell them what they thought might be done in the Institution to extend its useful-

ness. He was also requested by the Secretary to announce that the Council had re-elected him President for the ensuing year. He did his best to persuade the Council that he was not the right and proper person to take a second year of office, for the reason that he thought every Institution was the better for having fresh energy and fresh ideas brought to its service by its President from year to year. However, the Council were good enough to say that he had put his hand to certain propaganda and developments and they very much wished that he should continue, so that, being the servant of the Council, he had to submit to them. As some little set-off against that, the members would be glad to know that the Council had elected two or three new Members of Council, who would be extremely valuable, including Mr. Duckham, who would continue his system of taking round the hat, and Prof. Watts and Mr. John Smith. When the Council took up, as they hoped to do very shortly, the question of education, the accession of Prof. Watts in particular to the Council would be of special value.

The following paper was then read :—

Methods of Examination of Lubricating Oils.

By G. F. Robertshaw, *Member*.

The best introduction to a paper on lubricating oils to be read before this Institution, is a reference to the closing paragraphs of the Editorial in no. 15 of our Journal (April 1918). We are reminded, by a quotation from Young, that small things often very considerably affect the destinies of great ones, and the editor indicates how important is the detailed study of the selection, preparation, use and conservation of lubricants.

The objects of the present paper are to direct attention in a concise manner to a few aspects of this large subject, to afford a convenient reference to the somewhat extensive literature upon it, and to direct attention to useful sources of information, historical, scientific and practical, rather than to attempt to give a complete bibliography. References to the selection appended are prefixed by the letter B. Another object is to refer to the present lack of uniformity in the methods in use for the examination of lubricants and to the efforts being made to overcome the difficulties arising out of this absence of a recognised standard system.

Scientific and Industrial Research Department.—Early in 1917 the Standing Committee on Engineering appointed a Committee to report on the field of research in lubrication and lubricants. Two bulletins have been issued, one on cutting compounds, and the

other on solid lubricants. A comprehensive bibliography of research in lubricants, and a report on the work done by the Committee, and at the National Physical Laboratory are to be published.

One of the first steps taken by the Lubricants Committee in 1917 was to recommend that attention should be directed to the investigation of the quality of oiliness. In 1918 it was shown by Dunstan and Thole, that in lubricating oils unsaturation in constitution is undoubtedly associated in some measure with lubricating efficiency. (B 30.)

At a meeting of the Physical Society in November 1919 a discussion suggested by a paper on Oiliness and Lubrication by R. M. Deeley, resulted in numerous interesting references to recent work on this subject. The view expressed by the author is that the oil, or some constituent of the oil, enters into physico-chemical union with the comparatively rigid metallic surface, forming a composite film having the yielding nature of velvet pile, and he suggests that the best lubricants are those which produce the most easily sheared contact-film. During the discussion attention was directed to Langmuir's work on Surface Films, and H. S. Allen suggested that the property of oiliness depends upon the chemical forces called into play between the active part of the oil molecule and the solid surface of the bearing, and upon the nature of both the lubricant and solid surface. W. B. Hardy referred to the conclusion that the function of a lubricant is to reduce the energy of the surface, and thereby to reduce the capacity for cohesion, and the resistance to slip when two composite surfaces are applied the one to the other. (B 24.) Southcombe recalled his observation that the addition of small percentages of free fatty acid to a lubricating oil greatly lowers the surface-tension, and effects the same purpose as the addition of considerably greater percentages of glycerides. This observation has since been elaborated. (B 28.)

J. H. Hyde has determined the viscosities and compressibilities of liquids at high pressures and states that the absolute viscosity of all the oils which have been tested under such conditions increases considerably with pressure. (B 28*a*.)

L. Archbutt confirms this alteration of viscosity with increase of temperature, and points out that mineral oils are much more susceptible to this viscosity rise under conditions of pressure than castor oil. (B 26.)

W. B. Hardy demonstrates that the resultant lubricating efficiency under conditions of surface-contact is dependent on the nature of the surfaces, as well as upon the properties of the lubricant. Under

certain specified conditions of lubrication he finds that the lubricating power of the paraffinoid hydrocarbons increases with increasing molecular weight, that their acid derivatives lubricate better, and the alcoholic derivatives better still, the best lubricants being substances containing both carboxyl and hydroxyl groups. The reverse effect was obtained with derivatives of benzenoid hydrocarbons. (B 27.)

It appears from communications made by members of the Government Committee, and from a perusal of recent literature, that considerable advances have been made in the study of the problem of the true function of oil as a lubricant. It is possible that at some time in the future we may be in a position to apply to lubricants entirely new methods of examination, methods which will have a more exact relation to the true practical value of a lubricant than many with which we are now familiar. It should be the function of this Institution to draw the attention of everyone concerned with lubricants to any new methods of examination discovered, with a view to effecting such standardisation as may be necessary.

United States Bureau of Standards.—Early in February the 1919 report of the department concerned with lubricants was issued. The report points out that attention is being directed to the standardisation and comparison of viscometers, the investigation of chemical and physical tests, the relation between viscosity and friction, and the conditions necessary to obtain reliable results with friction machines.

Some of the questions referred to in the present paper may come within the purview of the Government Research Committee, but it is believed that the proposal that this Institution should also interest itself keenly in the question of the standardisation of methods of examining lubricants will meet with approval.

The valuable suggestion regarding standardisation made to this Institution by Mr. Duckham has been recently referred to, and it is apparent that considerable interest has been raised in this subject, and that this interest will ultimately result in work in the right direction. Sir Thomas Holland, speaking on October 21st, 1919, said that it was not possible to set up standards without much experimental work, and work could not be done without being paid for. This is true, but there is one way in which such work may be commenced, possibly without much difficulty, and continued until time has been found to define more surely the lines which further action should take. The method referred to, which affords an excellent illustration of a means of dealing with standardisation of analytical methods, is that adopted by the Society of Leather Trades

Chemists in England and the Leather Chemists Association in America. These two societies deal with the question of research into analytical methods on somewhat similar lines. Sectional committees of chemists are elected, and each committee acting under its own chairman deals with some particular research problem. Speaking generally, the work is done without expense to the Society, owing in some cases to the courtesy of the firms concerned. A moment's consideration will show that the problems before a committee on standardisation of the methods of testing petroleum products, and particularly lubricants, are different from those before a Leather Trades committee, in that they depend so greatly upon the types of apparatus used, and the liability to variation of the physical constants concerned. It cannot, however, be said that they are more difficult of application to such a mode of treatment than those before the leather trade, which has to deal with so many materials which are subject to rapid physical and chemical changes. It is needless to say that it would be necessary to appoint engineers to a committee on lubricants. The writer recalls a conversation with the late Sir Boverton Redwood touching on the question of standardisation. The first President of this Institution was very keen and enthusiastic on this subject, which he had made so peculiarly his own. May we hope that the mantle of his enthusiasm will fall upon us?

Lubrication.—The object of lubrication is the prevention of loss due to the production of excessive frictional heat and resistance. In an ideal system, this is effected by the use of precisely that lubricant best adapted to the particular purpose, and its application in the most efficient and economical manner. A lubricant, to be perfectly efficient, should possess sufficient viscosity and stability to enable it to maintain a lubricating film under all the working conditions required of it. With lubricated surfaces running at low speeds the friction produced, which tends to be high, depends on the load and nature of the surfaces, and is nearly independent of speed and area of surface. Lubricants used for such conditions should possess to a high degree that quality known as oiliness.

Where running speeds are high, and the supply of lubricant is good, conditions tend to approach what is known as perfect lubrication, where the friction produced is entirely due to the viscosity of the oil, and the viscosity of the lubricant necessary to produce perfect lubrication is proportional inversely to the speed and area, and directly to the pressure per unit of area.

In a journal running under favourable conditions of lubrication a pressure is set up by the oil film, and in reference to this pressure

attention has recently been drawn to the suggestion to substitute, when referring to lubricated friction, the expression "oil film resistance" per unit of area, for "co-efficient of friction."

LUBRICANTS.—There are several types of lubricants, each having many variations. These variations are made, either according to the use intended, or in accordance with a desire to conform to specification. They may result from the compounding of fixed oils with mineral oils, from the mixing of various kinds of mineral oil, or by the preparation of intimate mixtures of mineral oil with saponified or partly saponified fatty compounds. Any of these in turn may be mixed with solid compounds such as graphite.

Certain natural hydrocarbons are reduced or distilled, and used direct after purification.

FIXED OILS.—This term is not an entirely appropriate one, but is useful in describing those oils, other than purely hydrocarbon oils, which are used for lubrication. Of the fixed oils known, comparatively few are suitable for lubricating purposes, either alone or compounded. The usefulness of a fixed oil is fairly well-defined according to its liability to react with oxygen, and this liability is indicated by the iodine value, in that an oil of high iodine value usually oxidises readily. (Table 4.)

Chemically, fixed oils are divided into two groups, glycerides of fatty acids and esters of mono- and di-hydric alcohols. They are obtained from animal (marine and terrestrial) and vegetable sources, and are solid or liquid according to the temperature at which the observation is made. This point of the observation-temperature is important, owing to the fact that most natural oils and fats are liquid above 45° C. and solid at 0° C.

The observations concerning fixed oils in this paper are intended to refer to those only which are suitable in some way or other for lubrication. Some of the generalisations which may be made about such oils cannot be applied to certain other types of fixed oils. Natural fatty oils do not consist of pure triglycerides, but of mixtures of mono-, di- and tri-glycerides of various fatty acids. Glycerides may be split into glycerine and the corresponding fatty acids by a variety of well-known methods. This splitting, or saponification, viewed from the lubrication-standpoint, is of importance, because if a fixed oil is carelessly prepared, the percentage of free fatty acid present tends to be high. An oil containing a high percentage of fatty acid will, if applied as a lubricant, lead to the production of a metallic soap which has a tendency to produce such complications as gumming, increased friction, and pitting of the journal.

The pure fatty oils of greatest interest are castor, rape, olive, neatsfoot, tallow, lard and cotton-seed oils. These oils belong to the category of non-drying or semi-drying oils. Of the natural fats, tallow and palm oil are of interest. Certain blown oils are used in compounding, and fish oils have been used in lubrication, but where other oils are obtainable fish oils are not usually regarded with much favour.

The best types of vegetable oils are obtained by direct extraction without the aid of excessive heat, either with solvents or by expression in especially designed presses. This method of extraction results in the production of oils free from nitrogenous and mucilaginous impurities and of low acid value.

Castor oil, expressed from the seed of the Ricinus communis, consists almost entirely of the triglyceride of ricinoleic acid, $C_{17}H_{32}$-OH-COOH. This acid contains, in addition to the unsaturated bond, a hydroxyl group, and to this peculiar constitution the oil owes its remarkable properties. This oil was at one time considered to be the only oil permissible for use on marine engines, and during the war enormous quantities were used for aeroplane engines.

Recent tests performed in America appear to show that certain pure hydrocarbon oils are capable of very great service in this direction, and it is suggested that it may reasonably be anticipated that castor oil will, in time, be displaced as a lubricant by the hydrocarbon oils. The substitution of fixed oils by the hydrocarbon oils will some day be an important factor in relation to the production of edible oils. Many of the fixed oils which are used in the preparation of lubricants may be used in the preparation of edible oils, and a process is now in existence for the production of an edible oil from castor oil.

It is economically essential that fixed oils should, where possible, be used in the preparation of edible oils.

It is of interest to refer to attempts which are being made to prepare fats and fatty acids from petroleum. In the paper reference is made to the present world-shortage of live stock, and its effect on the production of fixed oils. (B 56*a*.)

Castor oil is not miscible with mineral oil, and when it is desired to use it compounded with mineral oils, it is necessary, either to use a certain percentage of other fatty oil in admixture with it, or to use the castor oil polymerised, in which form it mixes with mineral oils.

Olive oil is obtained by expression or extraction of the fruit of the olive, cultivated largely along the shores of the Mediterranean and in California. As the best brands of this oil are used for edible

purposes, those offered for lubrication require very careful examination for albuminoid material and other impurities.

Rape oil, which is expressed from rape seed, has usually a low solidifying-point. This oil was used as the standard for the Redwood Viscometer instrument. The rape oils now in use vary somewhat widely in their viscosities, and show figures different from that adopted as the Redwood standard.

The animal oils are usually prepared by hot digestion, in which operation speed of extraction is very desirable in order to reduce to the minimum the production of free fatty acids. Where necessary, fixed oils are refined by treatment with acid and alkali, by washing and filtration.

Blown oils are produced from fatty oils by the oxidising action of a current of air, usually at an elevated temperature. The hydroxylated compounds so produced raise the viscosity and specific gravity, and lower the flash-point of the oil treated. Blown cotton-seed oil and blown rape-oil are useful for compounding purposes. An ester of a dihydric alcohol of interest is sperm oil. This oil, chemically a fluid wax, is obtained from the head cavity of the Sperm whale, Physeter macrocephalus, and stands out from all other oils in its peculiar capacity for retaining viscosity with rise of temperature.

Mineral Oils.—Few natural crude mineral oils may be used as lubricants without preliminary treatment. Where viscous enough for such a purpose, they are usually clarified by settlement, and subsequent filtration through animal charcoal, fullers' earth and similar materials. The more usual treatment of crudes for the preparation of lubricating oils is either reduction or fractional distillation. Reduced oils are obtained from oils rich in lubricating oils by removal of such a proportion of lighter hydrocarbons as will leave the desired product. This removal is effected either by spontaneous evaporation or non-destructive distillation, preferably by the aid of a vacuum at low temperatures. Subsequent filtration and refining is resorted to where necessary, to remove objectionable matter. Where, in the distillation of hydrocarbons, the production of lubricating oils is the ultimate object, prevention of pyrogenesis is desirable, and the distilling vapours are cooled and collected rapidly. This object is effected by the use of horizontal stills, and distillation is aided by the use of superheated steam and vacuum. Methods of refining vary in detail according to the kind of crude, and each refiner has his own particular methods of operation. These methods may be roughly divided into

(1) Distillation to dryness in one operation.

(2) Distillation in two operations, where the lighter portions are first removed, and final distillation is subsequently effected in other stills.

(3) Distillation using the cracking process.

(4) Continuous, where the nature of the crude oil allows this.

The refining of petroleum has recently been dealt with in papers read before this Institution in 1916 and 1917, and later in a book (B 55), and requires only brief mention as consisting of treatment of the distilled oils with various reagents, H_2SO_4, NaOH, etc., and filtration through materials intended to remove colour, suspended impurities and carbonaceous matter. One of the troubles met with in refining, is the emulsification which may occur during and after treatment with acid and alkali. Numerous patents have been taken out for dealing with this problem. Several methods of breaking down emulsions are available, such as centrifugal treatment, selective filtration, aid of acids, electrical treatment and application of heat either alone or under pressure. It is stated that refining in a steam-pressure system gives little trouble, and that naphthenes, which emulsify with alkali, and sulphonic acids, which will emulsify in acid solution, are thereby successfully dealt with. (B 43.)

When mineral oils are to be used in the preparation of compounded oils or greases, they may, provided the flash-point is not low, be of comparatively low gravity.

When they are to be used alone as lubricants, they may be and are prepared having a wide range of viscosity and specific gravity. They may be divided, for general purposes into light oils, engine oils and cylinder oils. These three classes of oils have many variations according to their intended uses.

Materials such as stearic acid, oleic acid, rosin, rosin oil, Yorkshire grease, graphite, talc and steatite are used in the preparation of compounded and special lubricants.

The study of the preparation of lubricants involves the consideration of three parent types of product, oils, greases and special lubricants. The oil group includes pure hydrocarbon oils; pure fixed oils; compounded oils; mixtures of the foregoing in proportions appropriate to requirements; and oils containing materials giving fictitious viscosity.

Greases are usually calcium- or sodium-soaps, containing varying proportions of refined mineral oil, petroleum jelly or reduced petroleum.

The special group of lubricants include graphite and other solid materials, pastes and oils used during cutting or screwing, and oils

used for the lubrication of textiles. The war has drawn attention to new sources of lubricants such as coal-tar. Lubricating oils prepared from anthracene oil were used in Germany during the war, and it is stated that 150,000 tons per annum of such products should be available in the future.

A number of synthetic organic compounds have been used as lubricants, and patents covering the use of these compounds have recently been taken out, mostly in Germany. In view of the renewed activity in the shale industry it should be remembered that some shale-products have very useful lubricating properties. Of extreme interest to us is the hope which has been expressed, that our new shale industry will be able to give us large quantities of lubricating oil of good quality.

Physical Properties of Oils.

1. *Colour.*—The colour of lubricating oils varies from yellow and red in the pale oils, to green and black in the dark oils, and does not necessarily have any bearing on the utility of the oil, except where the oil has to be used for textiles, in which case a dark colour may do much damage.

2. *Specific Gravity and Density.*—In the fixed oils specific gravity ranges between ·870 (sperm-oil) and ·963 (castor-oil), and in mineral oils between ·860 and ·940. The specific gravity is not of much importance by itself, except where comparison is being made between oils of the same type, or between oils obtained from known crudes, or where the presence of impurities of high gravity such as rosin oil, tar oil, is suspected.

Density is essential in connection with work on viscosity, and may, when conjoined with the latter, give useful information.

3. *Boiling-Point.*—The boiling-points of mineral lubricating oils are usually well over 300° C., and do not usually afford much useful information, except where the examination of distillation-fractions is desired for special purposes, or where comparison against a standard is required. Fixed oils do not boil under normal pressure without decomposition and evolution of acrolein.

4. *Flash-Point.*—The flash-point of an oil may be defined as that temperature at which when slowly heated it begins to evolve vapour in such quantity that on application of a flame a momentary flash occurs, due to ignition of the vapour. It has been very well shown that the flash-point of an oil depends to some extent, on the apparatus employed and the method of operation of the test. (B 49.) The flash-points of lubricating oils vary from 300–700° F.

5. *Effect of application of Cold.*—Certain oils show a tendency to

deposit, or to thicken considerably, on cooling, and this property is of importance, and has to be considered where the oil is to be used cold. Certain mineral oils containing very small percentages of wax show very small tendency to deposit on cooling, and such oils are of great interest to the user of refrigerating machinery, or where lubrication under conditions of cold are in question. Those fixed oils which contain small percentages of saturated glycerides show small tendency to deposit.

6. *Viscosity.*—This is at the present time the most important measurable physical property possessed by lubricating oils. It is closely related to internal friction, and may be described as being due to the resistance which the particles of a liquid offer to their free motion over each other. It is not a definite measure of the lubricating value of an oil, but affords a very valuable guide where a selection is to be made from different oils. The viscosity of oils varies with temperature, decreasing with rise and increasing with fall. The rate of viscosity decrease with rise of temperature varies with different oils (Table 3) and this variation in rate, when measured, may be made to afford valuable information the practical importance of which is easily appreciated. All oils approximate in viscosity at 400° to 500° F.

7. *Oiliness.*—There is a quality possessed by good lubricants which is known as oiliness. This is, at present, an indefinable property, which gives to an oil under certain conditions of lubrication, the power to effect its purpose, and is a property which is not of necessity proportional to viscosity. Sir Boverton Redwood's statement that " The determination of the viscosity of an oil affords the most valuable test of the lubricating properties that we have at our disposal " is still true, but there remains that fact that fixed oils have usually, for the same viscosity, a greater oiliness than mineral oils.

8. *Surface Tension.*—There appears to be a doubt as to how much value should be attached to surface-tension as such, although it is clear that this property plays an important part in certain cases of lubrication.

Professor Boys (J.S.C.I., 1920, p. 58, T) has recently pointed out that the drop-number test as usually performed is not necessarily always a correct method for the comparison of surface-tensions of different oils, and drawn attention to the desirability of obtaining and expressing surface-tension results in absolute units.

The practical utility of the viscosity test may be, for certain purposes of comparison, usefully extended when mechanical testing is available. There are practical objections to judging the quality

of an oil on viscosity or mechanical tests alone, and the best results are probably obtained by the performance and correct interpretation of the results of both these tests, due regard being paid to chemical and other tests done with special objects in view.

9. *Volatility.*—Some oils, especially when kept at elevated temperatures show a tendency to evaporate, and a lubricating oil showing this tendency to a marked degree is liable to be wasteful in practice.

10. *Liability to Gum.*—The use as lubricants of certain oxidisable fixed oils liable to produce gummy deposits, and such mineral oils as may in time precipitate tar-like products, is to be avoided. Such oils increase the resistance due to friction in consequence of the drag. Numerous special tests have been devised in an attempt to recognise such oils, and to estimate the probable amount of gummy substance which will be produced under definite conditions of time and heat, without however giving absolutely reliable results.

The iodine value of a fixed oil is of importance as it indicates fairly definitely the liability of the oil to reactions which adversely affect lubricating properties. The practical importance of the iodine value of mineral oils is not very clear.

11. *Acidity.*—The acid content expressed as H_2SO_4, oleic acid or acid value is an indication of the presence of free fatty, rosin, naphthenic or sulphonic acids, or more rarely free sulphuric acid.

12. *Tendency to Emulsify.*—Certain mineral oils have a tendency to emulsify with water, and this property is of importance where cylinder crank-chamber and forced lubrication are in question.

An apparatus has been devised by A. Philip to estimate quantitatively this liability on the part of a mineral oil to emulsify. The Bureau of Standards has also published work on this question. In carrying out the test, the oil is intimately mixed with distilled water, and the mixture is allowed to settle. The conditions of experiment and apparatus are carefully specified. The percentage of oil separated in a definite time is reckoned as the demulsification-value of the oil. Mineral oils giving a value of 90 per cent. or over, have given satisfaction when used under practical conditions in steam turbines. This test is a good one for detecting small percentages of asphaltic material. Attention is drawn to the necessity for preventing the admixture of lubricating oil with fuel oil. (B. 119.)

Examination.

In referring to the examination of lubricating oils, it may be permissible to repeat, and to emphasize, the importance to all concerned of the efforts which are made from time to time to

standardise methods of test and the statement of results. The subject is admittedly large and somewhat complicated. Much work has been done by various committees and independent observers on standardisation of analytical methods and apparatus, and this will be referred to under appropriate headings. It is quite clear that no more appropriate sponsor for efforts in the direction indicated above, could be possible than the Institution of Petroleum Technologists, which represents every possible combination of interests, technical and commercial. It must be realised at the outset in efforts made towards agreement that the viewpoint of all should be considered, so that common ground for discussion may be found which will appeal to all concerned.

In the examination of lubricating oils, physical properties are as important as chemical, and the correct appreciation of the relation between physical and chemical tests is essential. In order to indicate the difficulties experienced when attempts are made to correlate the results of the analytical work of various operators using different methods, and to emphasize the necessity for standardisation, some of the well-known tests for lubricating oils are described somewhat in detail.

Although such a course necessarily entails repetition of many items of common knowledge, it is hoped that some indication will be made of questions requiring thought and investigation.

Specific Gravity.—In the statement of specific gravity, unless otherwise specified, comparison is usually assumed to have been made with water at the same temperature. This assumption cannot however be always accepted as correct, because this question appears to be dealt with in a somewhat haphazard manner, and it is usually impossible to say without further reference to those quoting the test, how comparison has been made.

Specific gravity is often quoted at 20° C. or 15·5° C. without reference to the density of water taken for comparison. The density of water varies with temperature as follows :—

Temperature	density
0° C.	0·99987
4° C.	1·000
15·5° C.	0·99912
20° C.	0·99823

The specific gravity is usually determined at 15·5° C.

Temperature plays an important part in this determination, as 1° C. represents in oils a difference in gravity of ·00066 to ·00062. Where rapidity of operation is of more consequence than absolute accuracy, a hydrometer is used. Hydrometer corrections are usually referred to the density of water at 15·5° C. as unity, the

instrument being used at the same temperature. On certificates of examination the liquids used for the purpose of correction are given, and it is pointed out that corrections are applicable only to the same liquids or to liquids of the same surface-tension as that used in the calibration test. In the consideration of the larger question of international standardisation, reference will be required to the American method of quoting Baumé.

10 Bé	= 1·00	Specific gravity.
20	= 0·933	„ „
30	= 0·875	„ „
40	= 0·8235	„ „
50	= 0·7778	„ „

An accurate method of determination is by means of some form of pyknometer. A specific gravity bottle with variations in form according to the type of oil, or a Sprengel tube may be used. The hydrostatic balance, where a definite amount of oil is displaced by a plummet usually carrying a thermometer and the specific gravity is shown by the weight on the arm required to balance the pointer, is in some of its forms exceedingly accurate. Where only a small quantity of oil is available, the specific gravity may be taken by immersing a drop of oil (carrying no air-bubbles) in diluted alcohol of such strength that the oil remains in the middle. The specific gravity is obtained from that of the diluted alcohol.

Flash-point.—The rapid or open test is performed by heating the oil in a crucible or other suitable vessel at a definite rate of temperature-rise until the application of a small flame causes momentary ignition of the vapour. It is essential to perform the test in a place free from disturbing draughts, and to keep to the details of size of container, amount of oil used, and rate of temperature rise as exactly as possible. (Table I.) There appears to be no definite rule for the performance of the open-flash test, and yet specifications often quote this figure without reference to the method employed in performing the test. It is necessary that form of apparatus and method of test should be standardised. Consideration should also be given to the restandardisation of thermometers. Corrections are usually obtained with total immersion, whereas for flash-points the correction should be made for a small immersion, of say one inch. The result given by the open-flash test usually differs considerably from the closed test, and the difference varies with different oils. The closed-flash test is usually performed in the Gray or the Pensky-Martens apparatus. These two forms of tester are similar in general outline, varying only in detail.

Volatility.—The tendency of oils to evaporate is of importance in two directions, cost and possible residue. An oil which evaporates to a serious extent at the working temperature cannot be an economical lubricant. Moreover, there may remain on the bearing after the evaporation of such an oil, a viscid or even a dry residue. The flash-point of an oil is an indication of its comparative safety in use, and may have no relation at all to its tendency to evaporate under conditions of heat. This tendency should be estimated by measuring the actual loss under definite conditions of time and temperature. This estimation may be made by subjecting the oil to the action of heat for a definite period of time, say ten hours, at such a temperature as may be decided by the type of oil and the use intended. As a result depends on the number of times the air is changed, attempts have been made to regulate the temperature and flow of air. The apparatus designed by Archbutt is intended to take this fact into consideration during evaporation tests. This apparatus consists of a strong copper tube of $\frac{7}{8}$ in. internal diameter, about 2 ft. long, having a branch tube 10 ft. long brazed into it near one end and coiled round the straight tube. This is fitted into an oven which may be heated to any desired temperature.

The ends of the straight piece, which project beyond the oven are closed brass screw-caps, one of which carries a small tube that acts as an air exit. The air or steam admitted through the coiled tube, after becoming heated in the coil, passes over the oil, which is contained in a small tray of inert material, 3 in. long, $\frac{1}{2}$ in. wide, and $\frac{1}{4}$ in. deep. The air current is maintained at a constant speed of 2 litres per minute. The oil, placed in the tray, is exposed to the action of the hot air or steam current for a definite period of time, usually one hour. The temperature is varied according to requirements. The volatility test, using air, gives a figure which represents the loss owing to vaporisation of the oil minus the gain due to oxidation. It is advisable to use a wide glass tube inside the copper tube, to keep a check on any loss due to possible accident or creeping of the oil. With air current controlled by a meter and temperature controlled by a thermostat, the writer has obtained results showing much greater concordance than those obtained by heating in open dishes. The open-dish method does not give satisfaction. On this point Mr. Radcliffe of the College of Technology, whose research work on oils is well known, has written as follows :—

"I have made many experiments with all kinds of apparatus, complex and simple, and do not think that any of my results are reliable. Another worker using the same method will probably arrive at a materially different result, and at present so far as I

know, there is no reliable method for determining the loss by evaporation which occurs on heating mineral oils. This should be qualified by the statement, that, lubricating oils which only lose very small amounts on heating may be examined by Archbutt and Deeley's method with fair concordance."

An interesting variation of this test may be obtained by using the apparatus used for the transformer-oil sludge-test, and drawing through the oil, kept carefully at a definite elevated temperature, a dry current of air passing at a fixed rate. The oil vaporised is collected in one or more cooled U-tubes, and may be examined. The difficulty of arriving at satisfactory results by heating in open vessels is increased by the variety of the methods quoted as used for the test. Actual specifications of evaporation-tests made on a type of oil used in every case for the same purpose show the following variety in the data furnished :—

Temperatures, 100° C., 150° C., 190° F.: Time of heating 6, 8, 10 hours. Vessels of glass, porcelain or unnamed material, of circular or other form and varying dimensions. Quantity stated by bulk, weight or not at all. Method of heating mentioned in but few cases.

Cold Test.—There are several methods in use for performing this test, and a description of the variations will illustrate the difficulty which arises when a test is returned without reference to the method used.

1. The cold test is performed by gradually cooling down the oil under stirring. The temperature is noted when separation takes place of paraffin wax or other solid material such as, in the case where fixed oils are present, saturated glycerides.

2. The pour test is generally used with black or other oils such as those which contain amorphous compounds which become solid at low temperatures without showing that separation characteristic of paraffin wax. The temperature is noted when (*a*) flow ceases, or (*b*) when on subsequent warming flow recommences.

3. Scotch test. The oil is cooled down, and the temperature noted at which, on warming again, the last trace of paraffin wax disappears.

4. A definite viscosity may be decided upon as a standard, and the temperature at which this viscosity is attained may be noted, and taken as the cold test.

5. The oil is compared against a sample of known properties by any of the above methods.

Where a number of oils are to be compared, known weights may be subjected to successively lower temperatures for definite periods

of time, and an examination of their behaviour made and compared with the standard.

The Tagliabue standard tester is the outcome of an effort to standardise the cold test. It consists of a heat-isolated ice-chamber, surrounded by non-conducting walls, and having special arrangements for noting the effect on oil of the lowering temperatures. A method of comparing the properties of a number of oils under conditions of cold consists in cooling down definite weights of oil in glass vessels of similar shape and size in the brine water of an ice plant. Here the temperature remains the same over long periods of time, and useful practical results may be very easily and quickly obtained.

It should be carefully noted that an oil should not be used twice for the cold test, and that the time-factor and details of test performance are of great importance. (Table II.)

Gumming Test.—The nitro-sulphuric acid test, mixing 5 grammes of an oil with 11 cc. of acid, is said to give a good indication of the liability of an oil to gum under working conditions. The acid used for the test is obtained by saturating H_2SO_4 76° Bé containing a small proportion of HNO_3 with nitric oxide at 0° C.

Gill points out that mineral oils which give very dark-coloured matter when treated with equal proportions of H_2SO_4 are liable to have gumming tendencies.

Kissling has suggested two methods for estimating the liability to gum. (1) 50 grammes oil is heated in an oven 125–135° C. for five days of twelve hours each, and then washed with petroleum ether into a 500 cc. flask. The flask is made up to the mark, allowed to stand twelve hours, when the liquid is filtered. The weight of insoluble matter is taken as gummy material, and reckoned out as a percentage on the weight of the original oil. (2) 50 grammes of oil shaken with 50 cc. of alcoholic soda (50 grammes 7·5% NaOH, and 50 grammes 99% alcohol) at 80° C. The mixture is extracted first with ether, and then with benzene. The latter solvent extracts the tarry matter, which is obtained by driving off the solvent.

Richardson and Hanson (B 100) suggest that a good method of testing the value of a lubricating oil is to expose it in very shallow layers in an oxidising atmosphere at a high temperature for twelve hours, and then to observe the refractive index. An increase in refractive index would show polymerisation and tendency to gum.

Viscosity.—Before giving a description of viscosity-determinations, it will be useful to state a few of the present methods of expression of viscosity-values.

REDWOOD. The number of seconds occupied by the outflow of 50 cc. of oil is multiplied by 100, and divided by 535 (the number of seconds for the outflow of a certain rape oil from the apparatus). The result is multiplied by the specific gravity of the oil and divided by the specific gravity of rape oil (taken as ·915). Alternatively the number of seconds is expressed as a percentage of 535.

ENGLER. Specific viscosity is the time of outflow of 200 cc. of oil divided by the time of outflow of 200 cc. of water at 20° C.

SAYBOLT. Specific viscosity. The time of outflow of 60 cc. of oil compared with the time of outflow of water.

DOOLITTLE. Results are expressed in terms of granulated sugar contained in 100 cc., of syrup at 60° F. which will at 80° F. give the same retardation as the oil.

COLEMAN, ARCHBUTT. Either relative viscosity expressed in terms of the viscosity of a standard liquid, or absolute viscosity.

LIDSTONE, OSTWALD, MICHELL. Absolute viscosity.

It is apparent from the foregoing examples that there is a need for the standardisation of viscosity-expression. Many appeals have been made from time to time that absolute viscosity or some convenient multiple thereof should be used as the standard method of expression. Such a method of expression affords some quantitative idea of the power lost through defective lubrication. Absolute viscosity may be converted into lbs. per square inch by the formula

$$a = \frac{B}{69{,}000}$$

Where a = lbs. per square inch

B = dynes per square cm.

Further, a temperature-absolute viscosity curve is useful in showing at what temperature an oil ceases to be an efficient lubricant.

The suggestion that the viscosity unit be known as poise, with centipoise (·01 poise) as the practical unit, has met with some favour. As this value approximates very nearly to the viscosity of water, the viscosity of an oil expressed in centipoises would be the same as its specific viscosity at the same temperature.

Poiseuille first demonstrated that the rate of flow of a liquid through a capillary tube is, proportional to the pressure and inversely proportional to the length of the tube and proportional to the fourth power of the radius of the bore.

The paper by Drs. Dunstan and Thole on "The Relation between Viscosity and Chemical Constitution of Lubricating Oils" in vol. iv of this journal, should be consulted for a clear explanation of the conditions which affect viscosity-determination. The accepted physical definition of viscosity is that the viscosity of a substance

is measured by the tangential force on unit area of either of two horizontal planes at unit distance apart, one of the planes moving with unit velocity relatively to the other, the space between these planes being filled with the viscous substance.

The problem of standardisation of instruments has been ably dealt with from two standpoints, one, the conversion of the results given by commercial viscometers into absolute units, and the other, the sources of error to be eliminated when determinations are made with commercial instruments. As more becomes known about oiliness, it is possible that the determination may lose some of its importance, but there is, at present, general agreement as to its usefulness.

The earliest type of viscometric test was made by comparing the time taken by drops of oil of equal size to fall down an inclined plane under definite conditions of temperature, with the time taken by a given standard oil.

The second type of test is a comparison of the time taken by equal volumes of two liquids, to flow through a narrow aperture under exactly the same conditions.

A third type is a torsion-measurement test, where the resistance offered to the untwisting of a wire by the viscous oil is measured.

The fourth type is represented by a new and interesting apparatus called the Michell viscometer.

Efflux Viscometers. 1. *The Redwood Instrument.*—In England the standard efflux viscometer is that designed by Redwood. This instrument consists of a silvered copper cylinder $1\frac{7}{8}$ in. diameter and $3\frac{1}{2}$ in. depth. On one side projects a tube for heating, and on the other a tap for drawing off water. The base of the inner cylinder is pierced by an agate jet hollowed hemispherically around the aperture, which is about ·067 in. diameter. This is fixed in a metal ring which is screwed into the bottom of the inner cylinder. The cup-shaped mouth of the agate jet can be closed by a small silvered brass ball attached to a strong wire. The height of the oil is accurately registered by means of an inverted projection. A round bulbed thermometer is used for temperature registration. The surrounding liquid is kept at an even temperature by agitation. Levelling screws and spirit level are provided to enable accurate levelling, 1° tilt causing 0·4% change in efflux time. (B 3.)

The viscosity-determination is effected as follows :—

The jacket is filled with water for temperatures up to 95° C. or with oil for higher temperatures, to a point roughly corresponding with the level of liquid in the inner cylinder. The surrounding

liquid is then brought to the desired temperature, and the oil to be tested, previously filtered and heated to the correct temperature, is poured into the inner cylinder until its level coincides exactly with the point of the gauge. This adjustment must be exact, as a variation of 1 mm. causes error in the result of 1·3 %. The variation of viscosity with temperature necessitates an accurate maintenance of even temperature. Where the temperature of determination is considerably above that of the room, the measuring flask should be kept at the test temperature, and the outside bath 2° or 3° higher. When the correct temperatures are registered, the ball valve is raised, and the time in seconds taken in filling the flask to the correct mark is noted. The following formula for the direct conversion of Redwood readings into absolute viscosity is of interest :—

$$\gamma = (0{\cdot}0026\,T - \frac{1{\cdot}715}{T})\delta = (0{\cdot}0026\,T - \frac{1{\cdot}715}{T}\delta$$

where γ and δ are the viscosity in C.G.S. units and density in grammes per cc. respectively, of the liquids under examination, and T is the time of outflow in seconds from the Redwood instrument. (B 3.)

2. *The Engler viscometer* is the type used extensively in Germany. This vessel is closed by a lid, and has a slightly projecting delivery tube of standard size. Accurate levelling is effected by reference of the height of oil to three pointers. One mm. variation in setting initial height affects the outflow to the extent of 2·5 %. The outer vessel completely surrounds the inner vessel and efflux tube. The inner cylinder holds 240 cc., and the flask is marked at 200 and 240 cc. The plug, which is of hard wood, is raised when the oil is at the correct temperature and perfectly still, and the efflux time is noted. An error of one mm. in setting the level changes the efflux time 0·8 %.

3. *The Saybolt viscometer*, which has recently been adopted as the standard instrument in the United States, has a cylindrical inner tube, surrounded at the top by a gallery into which excess of oil flows, and from which it may be removed by a pipette. The cylinder terminates at the lower end in a metal jet of a standard size. The oil is run into a flask marked at 60 cc., and the time taken to fill to this mark is taken as the efflux time. The Saybolt viscometer may be very easily adopted for determinations at constant temperature just below the boiling-point of water by surrounding the inner cylinder with a steam chest.

4. *The Richlé-Stillman* instrument has a conical inner cylinder adapted for dealing with quantities of oil not exceeding 100 cc.

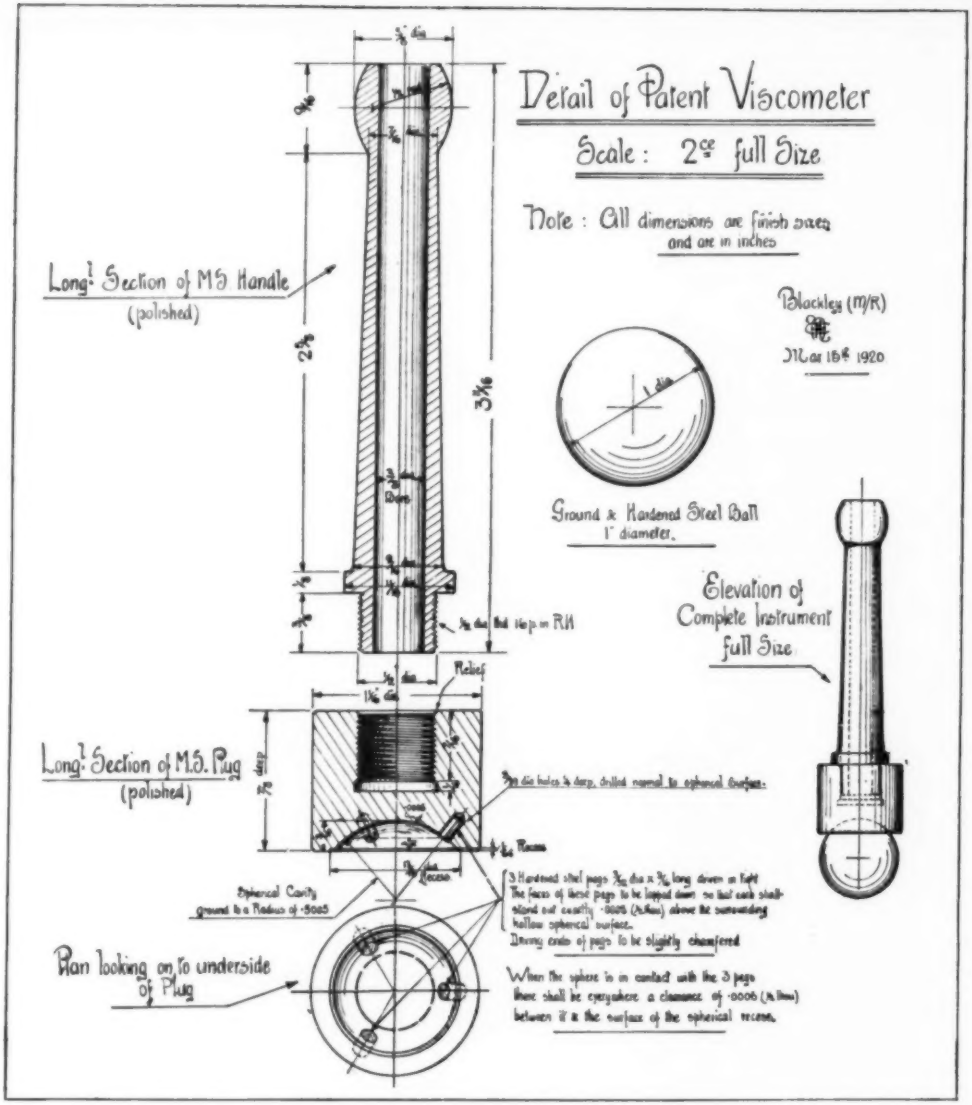
Detail of Patent Viscometer
Scale : 2ᶜᵉ full Size
Note : All dimensions are finish sizes and are in inches
Blackley (M/R)
Mar 18th 1920
Long.l Section of MS Handle
(polished)
Ground & Hardened Steel Ball
1" diameter.
Elevation of
Complete Instrument
full Size
Long.l Section of M.S. Plug
(polished)
Spherical Cavity
ground to a Radius of .5005
Plan looking on to underside
of Plug
3 Hardened steel pegs
When the sphere is in contact with the 3 pegs
there shall be everywhere a clearance of .0006
between it & the surface of the spherical recess.

FIG. 49.

The efflux is closed and opened by a rapidly-working rack-and-pinion arrangement.

5. *The Ostwald viscometer* is a glass instrument which gives results with small quantities of oil. It consists of a U tube having one limb a capillary tube through which the rate of flow of oil is noted and compared with a given standard.

6. *The Coleman-Archbutt* instrument is made of glass, and is capable of giving useful data at various temperatures up to 212° F. It is an improved form of the instrument designed by Coleman. For the determination of absolute viscosity the instrument may be standardised against glycerine or other pure compounds having definite known viscosities. The test may be made, if necessary, with 25 cc. of oil.

7. *The Lidstone* instrument was designed for the measurement of the viscosity of small quantities of liquids, and has been spoken of favourably. Use is made of the flow of mercury between two fixed points. Reference to the original communication (B 82) should be made for details, and for a modified mercurial viscometer for use with volatile liquids.

8. *The Künkler viscometer* was designed for use with small quantities of oil.

9. *Michell viscometer*, fig. 49. This is a new type of instrument, designed to give the viscosity of a fluid in absolute units. Most of the viscometers in use depend on the application of Poiseuille's law to the efflux through a capillary tube of liquid. The use of efflux viscometers involves corrections for acceleration due to gravity, density, variation due to differences in head, surface-tension, etc. These methods are capable of great refinement and accuracy, but require the spending of much time, and the employment of great care, especially where temperature-viscosity curves are required.

The Michell instrument is a simply designed, substantially constructed, practical instrument, which whilst designed primarily for Works use, is also capable of giving very concordant results. It consists of a cup of hardened steel having a concave surface which has upon it three very slight circular projections, which prevent the steel ball from making complete contact, and which regulate the thickness of the film of fluid under test. For protection and accommodation of a small surplus of oil, the cup is slightly recessed round the edge. The handle of the instrument has a pocket for the thermometer.

For approximate readings sufficient of the oil to be examined is placed in the cup so that when the ball is placed in position the circular recess is completely filled. The whole is then inverted

and the cup and ball firmly and carefully pressed together with a steady pressure of about 7 lbs., the instrument being held at the top to avoid heating. After 5 seconds steady pressure the viscometer is raised about an inch, held steady and vertical, and at the same instant a chronometer is started. The number of seconds between the lift of the instrument and the fall of the ball is noted, and this number, divided by the constant of the instrument, gives the viscosity of the fluid under test, in absolute units.

Immersion.—In the method which is performed when great accuracy is required, the instrument is completely immersed in oil at a desired constant temperature, in such a manner as to observe all those precautions necessary to prevent interference from outside disturbances, and in such a way as to ensure, by tilting, that no air is trapped between the cup surface and the ball. The thermometer pocket is filled with oil to ensure accurate temperature-reading. The method of applying pressure is important. Constant pressure is applied for 5 seconds, then released for one second, and the instrument is then raised from the bottom of the container. This method prevents irregularity in lift-timing. Temperature-viscosity curves may be taken by heating to the desired maximum temperature and taking observations at that, and successively lower temperatures. Thermal insulation is obviously a necessary precaution.

The Balance method requires special apparatus, and is a refinement of method and apparatus whereby the viscosity of a gas may be measured.

The principle of operation of the Michell viscometer with liquids is as follows :—When the support is taken away from under the ball, its downward movement immediately commences. The oil film of fixed initial thickness being now subjected to tension stretches and becomes thicker. This causes it to contract towards the centre, oil from the outside circular groove coming inwards. The downward movement of the ball is retarded by the viscous fluid having thus to flow inwards to counteract the vacuum-forming tendency at the centre. The ball is released from all restraint and falls away from the cup when the film, which partially supports it, becomes so thick that it is no longer able to sustain the weight against gravitation. The rate of this thickening of the film is proportional to, and affords a measurement of, the viscosity of the oil. Reference is made to the Michell instrument because it is believed that engineers will be interested in a non-fragile instrument which may be carried about in the pocket, and give comparative data of great usefulness.

Doolittle Torsion Viscometer.

This apparatus consists of a steel wire connected to a cylinder 2 in. by 1½ in. suspended in such a manner, that measurement can be made, of the resistance which an oil under examination offers to the free motion of the cylinder, which tends to rotate as a result of torsion of the twisted wire. The wire is twisted through a definite number of degrees, generally 360°, and the retardation noted. The first reading is taken at the end of the first swing, and the second at the end of the next swing in the same direction.

Record	Swing to right A°
	Swing to left —
	Swing to right B°
	Retardation noted A° — B°

In order to eliminate error the wire is twisted the other way, and the mean result taken. The instrument is standardised by using cane-sugar solution of known strength. The observations made with this instrument are independent of gravitation, and may be made at any desired temperature and with oils containing a moderate amount of suspended matter.

Friction Tests.

There is no published method for the laboratory determination of oiliness, and it is desirable that, where convenient, chemical and physical tests should be supplemented by friction-tests. The design of mechanical testers varies according to the object in view during test. It may be desired to test different methods of lubricant application; differences in metal or alloy forming the bearings; behaviour of an oil under high-temperature or at ordinary temperatures under varying conditions of speed and load; durability; liability to oxidation, gumming or other changes during use.

Thurston Machine.—This well-known machine was invented by Professor Thurston, and consists of a pendulum hung from a bearing on a shaft rotated by means of a pulley. The bearing is clasped by two brasses, and the pressure thereon caused by a spring inside the pendulum may be regulated by means of a milled head and screw. The pressure per square inch, and also the total pressure on the journal, are indicated on the index-plates. The total friction may be read on the scale of the arc. When the shaft is set in motion, the friction between it and the brasses causes the pendulum to deviate from the vertical and to indicate the total friction. A thermometer is fitted in the upper brass to indicate the temperature during a test. This machine is made in various

sizes according to the nature of the requirements of the test, the larger sizes being self-recording. The writer has, by the use of resistances placed in the electric circuit connected to the driving motor, arranged a small machine to run at speeds which may be made to vary from very low to very high, and has found that this arrangement helps materially towards obtaining useful results.

A large mechanical tester was made by Sir Wm. Bailey & Co., Ltd., for the Government. This machine was designed for testing oils with bearing speeds up to 10,000 ft. per minute, with pressures up to 120 lbs. per sq. in., and also speeds up to 6,000 ft. per minute and pressures up to 500 lbs. per sq. in. On the official test the maximum speed of 10,000 ft. per minute was obtained with a bearing pressure of 300 lbs. per sq. in. As this machine is an example of one of the largest ever made for the purpose, four blue prints are shown by the courtesy of the makers.

The *Marten* machine is a modification of Thurston's, in which lubrication is effected by running in an oil bath. The bearings are arranged so that constant temperature may be kept during the running of a test.

Benjamin's machine has an oil groove in the top-bearing, and pressure may be applied top and bottom. The oil is fed at a constant rate for two hours, friction and temperature being recorded every few minutes. The oil supply is then stopped, and the time noted when the oil ceases to lubricate, an idea being thus obtained of the durability of the oil.

In running a test on the *Ingham & Stapper* machine the oil is placed on the journal, and the total number of revolutions made when the temperature has reached 200° F. is noted.

The *Stroudley* machine was designed to give results comparable with those which obtain in running locomotives. The machines designed by *Macnaught* and by *Woodbury* are of the disc and collar type.

Reference to the patent list will show that many forms of friction-machines have been suggested.

The difficulty from the practical point of view, of exactly defining the utility of the mechanical oil-tester, lies in the fact that the nature of the bearing surfaces and conditions of running are usually different from those met with in practice.

At the meeting of the Physical Society previously referred to, Dr. Stanton drew attention to useful results which had been obtained at the National Physical Laboratory with the worm-gear testing-machine designed by Lanchester.

Mr. Deeley described a small machine designed to measure the

oiliness of lubricants under conditions of metallic contact. This instrument was recently referred to by Archbutt, who states that very useful results have been obtained with it in measuring the static friction between solid surfaces under varying conditions.

Free Acidity.—Free organic acidity present in light-coloured oils may be estimated by direct titration in alcoholic solution. When the oil is dark in colour the free acid is washed out in neutral alcohol and titrated. Free mineral acid is of comparatively rare occurrence. Certain sulphonic acids which are liable to be present in lubricating oils which have been refined by a sulphuric acid treatment, are not decomposed easily, and require long boiling or treatment with superheated steam where an estimation of the SO_3 content is required. It is usual to return acidity as oleic acid.

Water.—Where possible, direct methods of estimation such as direct heating in air-bath or over flame should be avoided, as these methods give only very approximate results. Distillation with petrol or zylol gives results correct to a small percentage. With pure mineral oils, and for the estimation of small percentages of water, measurement of evolved acetylene or hydrogen may be used. Correction for the solubility of acetylene in an average mineral oil of about 1·1 times its volume has to be made. There is some doubt whether this method is applicable to mixtures containing fixed oil. In the writer's experiments difficulty has been found in obtaining complete concordance, and the work is to be continued. The method described by A. Philip recently could presumably be adopted to estimation of water in lubricating oils, provided the obvious precautions are taken.

Tarry Matter.—The liability of mineral oils to deposit tarry matters may be subjected to examination by solution in light petroleum solvents. Certain asphaltic substances are insoluble in petroleum ether, and may be examined after extraction and separation by this method. Where it is desired to use this test quantitatively, the time factor becomes important, as the quantity of insoluble matter obtained depends up to certain limits upon the time used in effecting solution, and allowing to stand.

Compounded Oils.—The general principles of the estimation, separation and examination of the unsaponifiable and saponifiable portions of compounded oils are well understood. The use of high-boiling alcohol during saponification is useful for time-saving, and particularly so when cholesterol is present.

Quick drying of an extracted oil is effected by the addition of benzene-alcohol mixture or acetone, either of which materially hasten the drying process.

Oils which show unnaturally high viscosity for their type are examined for compounds, such as aluminium soaps, which give a fictitious viscosity.

Solidified oils consist of mineral oils made solid or gelatinous by means of sodium, calcium or aluminium soaps. They are prepared either by dissolving soaps in mineral oils, or by mixing fixed oils with mineral oil, and then saponifying either partly or completely.

Lubricating greases consist of semi-solid or solid emulsions containing fats, fatty oil, fatty acids, mineral and other unsaponifiable oils, rosin oil, wool grease, etc., the emulsification being effected by lime or caustic soda. Greases for special purposes contain graphite. No definite rule can be accepted for the examination of a lubricating grease, owing to the great variety of products used in manufacture. They should be examined for water, loss at 100° C., free alkali, free acid and filling materials.

Fibre Lubricants.—In order to withstand the mechanical processes involved in the preparation of cotton and wool fabrics the fibres are lubricated. The ideal oil for this purpose is one which is easily removed by soda during scouring.

Cutting Lubricants.—These compounds either in the form of liquids or paste are used during screwing, cutting and grinding. The subject is dealt with in Bulletin No. 2 of the Department of Scientific and Industrial Research. In this document attention is drawn to the liability to skin troubles of workers on screwing machines, and precautions to be observed are suggested.

In February 1920, Bulletin No. 4 of the Department of Scientific and Industrial Research on Solid Lubricants was issued. This memorandum deals with the characteristics, action, and method of application of solid lubricants, analysis and grading of graphites, practical considerations and observations on results obtained by the use of solid lubricants. In the prefatory note, attention is drawn to the present incomplete state of our knowledge on certain theoretical questions of fundamental importance to users of lubricants. Numerous questions of great practical interest are dealt with, including hot bearings, practical limitations to the use of colloidal graphite, lubrication of worm-gears (always a difficult problem), steam engines and internal-combustion engines.

Practical considerations lie primarily within the sphere of the engineer's activity, and cover a very large and debatable field. The good quality of the best possible oil will be of no avail unless the bearings and oil-feed systems are designed for maximum efficiency. This question is of as great interest to the petroleum

technologist as to the engineer, because efficiency in these directions means conservation of oil.

Considering how well the various interests concerned in the supply of lubricants deal with the various problems of lubrication from the engineer's point of view, and how forcibly most of their representatives point out that the physical and chemical tests performed in the laboratory must, in order to be entirely useful, be viewed in the light of practical results, it is easy to appreciate how difficult is the task of one who is asked to adjudicate between the claims of various suppliers. Some experts go so far as to claim that only the practical test may be considered as the criterion of a lubricant's value. This, obviously, goes too far, as much loss and damage could be sustained before a bad oil was rejected. The general difficulty indicated is accentuated by the fact that there are so many ways of performing tests, quoting results, and drawing up specifications. It has been amply proved that collaboration between engineer and chemist on the subject of lubrication is attended with the greatest advantage. When specifications are insisted on by the user, it is essential that they be drawn up, after collaboration between engineer and chemist, in such a form as to render possible the application of known methods of examination. In considering the ideals to be aimed at by all interested in lubricants, it must be remembered that the question requires to be viewed from several points of view. The manufacturer is interested to know the exact conditions under which his products are to be applied, with a view to providing the correct oil for each purpose. It will be necessary to keep in view the demands for other types of petroleum-products, because although we are assured by the very highest authority that the petroleum industry will meet all these demands in the future, we may yet come to a day when the rival claims will require to receive serious consideration. The elimination as far as possible of the use of potential foodstuffs (glycerides) is a problem now receiving serious attention. The recent claim for the properties of small percentages of free fatty acids has an interesting bearing on this question.

The makers, owners and operative engineers in charge of machinery are concerned with the greatest reduction of friction for the least cost. The consideration of economy, efficiency, cleanliness and conservation comes within the province of the maintenance-engineer, and his problem is to keep in view every phase of these important questions at the same time.

Every Works using quantities of lubricants should have a centrally-placed oil store large enough to ensure cleanliness, and

having arrangements for the recovery of waste oil. It appears to the writer that those who have not given serious consideration to this question of conservation would do well to refer to the work done in this direction by firms who have made a special study of it. A description of one method is referred to in the bibliography. (B 192.)

Many schemes have been suggested to keep a check on the consumption of oil; the writer considers that a scheme which arranges to account for, and accurately indicates the destination of every gallon of oil used, is the only safe one. It is only by accounting in money value for oil used, that due appreciation is obtained of any excessive or wasteful usage.

In addition to the short bibliography appended hereto, that at the end of the Paper by Dunstan and Thole and the list of books in the Institution library should be consulted.

TABLE I.

Containing Vessel.	Cc. Oil.	Distance of oil from top. Inches.	Depth of oil. Inches.	Surface diam. Inches.	Flash-points.	Working in draught and without due care.
Pensky-Martens, Closed	75	0·8	1·4	2·1	330	—
Enamel Basin...	100	1·0	1·2	2·9	345, 343	352
Pensky-Martens, Open	75	0·8	1·4	2·1	343, 343	348
Crucible, Nickel	20	0·15	1·05	1·3	347, 349, 345	358
Silica Crucible	20	0·4	1·85	1·7	345, 345, 352	364
Metal Cup ...	80	0·35	1·05	2·5	347, 343, 342	370
Tin (1 lb.) ...	200	0·6	1·0	4·3	343, 348, 345, 342	

TABLE II.—COLD TESTS.

Scotch Test.	Mineral Oil Used.	Volume of Oil used.	Treatment.	Lowest Temperature.	Appearance of Oil at Lowest Temperature.	Temperature of Disappearance of Cloudiness.	Average Temperature at Close of Test.	Remarks.
No. 1	Scotch	50 cc.	Cooled 3 minutes. Removed and allowed to warm up with shaking.	+4° C.	Oil had commenced to solidify.	+10° C.	+11° C.	Room temperature throughout about 20° C.
2	Sp. G. 0·8867 at 15·5° C. / 15·5° C.	50 cc.	Cooled 24 minutes. Shaken up during warming.	−11·5° C.	Completely solid.	+8° C.	+8·5° C.	
3	Viscosity 0·376 at 15·5° C.	50 cc.	Cooled 24 minutes. Warmed up without shaking.	−11·5° C.	Completely solid.	+4·5° C.	+6·5° C.	
4	Mexican	50 cc.	Cooled 30 minutes. Shaken during warming.	−7° C.	Consistency of a normal butter.	+8° C.	—	Repeat tests showing that concordance is possible when conditions are exactly the same.
5	Sp. G. 0·916 at 15·5° C. / 15·5° C.	50 cc.	Cooled 30 minutes. Shaken during warming.	−7° C.		+8° C.	—	
6	Viscosity 0·488 at 15·5° C.	50 cc.	Cooled 30 minutes. Warmed without shaking.	−7° C.		+7° C.	—	

Pour Test.				Pour Temperature.	
1	Scotch	*50 cc.	Cooled 60 minutes	−4° C.	−4° C.
2	,,	50 cc.	Cooled 70 minutes	−4·5° C.	−4·5° C.
3	,,	50 cc.	Cooled 80 minutes	−5·5° C.	−5·0° C.

*The pour temperature is dependent on quantity used. With larger quantities test tends to show lower figure.

Temp. of Cease of Flow of Oil.				Temp. of Flow Cease.	
1	Scotch	50 cc.	Undisturbed	−4·5° C.	
2	,,	50 cc.	Disturbed during cooling	−8·5° C.	Repeat tests.
3	,,	50 cc.	Disturbed during cooling	−8·5° C.	

Table III.

Oil.	Viscosity at 70° F. (a)	Viscosity at 140° F. (b)	$\frac{100 \times b}{a}$	$\frac{a-b}{70}$
Sperm Oil	·3417	0·0942	27·5	·0353
Olive Oil	·76	0·18	23·7	·083
Rape Oil	·95	0·2	21·0	·107
Scotch Oil ·8875 ...	·287	0·068	23·6	·0313
American Oil ·8943 ...	·4135	0·0812	19·6	·0474
Mexican Oil ·9009 ...	·35	0·0732	20·9	·0393
Russian Oil ·9098 ...	3·238	0·282	8·6	·422
Castor Oil	—	0·79	—	—
Polymerized Castor Oil	—	1·07	—	—

Table IV.

Iodine Values.		Average Values.
Castor Oil ...	87	
Rape Oil ...	102	
Olive Oil ...	85	
Neatsfoot Oil ...	82	
Lard Oil ...	67	
Cotton Seed ...	110	
Tallow	43	
Fish Oils ...	160	Vary very widely
Sperm Oil ...	90	

Lubricating Oils.

	Imports. Gallons.	Value Total £.	Value per Gallon.	Re-Exports.	Value Total £.	Value per Gallon.
1912	65,327,061	2,059,797	0·603/-	1,178,433	57,656	0·98/-
1913	67,962,493	2,472,514	0·727/-	1,112,414	60,851	1·09/-
1914	66,646,512	2,340,982	0·702/-	1,060,222	59,093	1·11/-
1915	76,792,165	2,902,022	0·755/-	1,823,946	84,228	0·923/-
1916	83,167,754	5,295,113	1·27/-	913,058	83,539	1·82/-
1917	87,779,737	7,147,980	1·74/-	1,027,784	119,393	2·32/-
1918	102,273,841	10,839,880	2·12/-	935,067	125,040	2·67/-
1919	65,832,998	6,854,447	2·08/-	4,330,015	594,496	2·72/-
1920—January	6,609,693	835,764	2·47/-	206,070	28,830	2·79/-
February	6,892,257	831,527				

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DISCUSSION.

The President said he desired on behalf of the Institution to propose a most hearty vote of thanks to the author for what he thought might very properly be described as a most suggestive and comprehensive paper. The author had added to the suggestions that were made by Mr. Arnold Philip, in the paper read at the first meeting of the session, that the Institution should lend its aid in connection with the question of standardisation. All the members recognised that that was a very big task, which he was afraid the Council at the moment had put aside until some more convenient opportunity occurred. In the meantime, as the author had reminded them in the paper, there were Government Departments and Research Committees that were to some extent dealing with the subject, and he had heard it rumoured that at the Crystal Palace Exhibition to which he had previously referred it was possible there might be some kind of International Conference organised by the Government, at which a number of interesting petroleum questions would be discussed, from the point of view not only of our own nation but of others, which would throw a good deal of light upon the subject. Personally he did not think the Institution could take all the burden on its shoulders. Its function might perhaps be to give advice and assistance to some

of the Departments and Government Committees, but he thought he could promise for the Council that it would examine the whole subject at the earliest opportunity, and see what were the possibilities of doing good work in that connection.

Dr. Ormandy said the author had in his paper brought together a very large amount of information, and had laid stress on the point which had been emphasised at the meetings of the Institution on very many previous occasions, namely, that standardisation was required. It was quite obvious that, in so far as the testing of oils depended on the utilisation of purely empirical rules, so much the more was it necessary that those rules and regulations should be properly laid down. This country, however, was not an oil producer but a large oil user. There were other countries, particularly the United States, that produced oil and used it in quantities compared with which the use in this country was a mere bagatelle. The United States possessed a Government service which on the whole was x to the nth time more intelligent than our own. It published bulletins of work which had been done for the benefit of its army, navy and the people at large. On the other hand he was afraid that our own Government Departments, although they did much more research work than the public generally knew, to a very large extent reserved the result of that work and did not reveal it for the benefit of the public. The President had informed the members that there was a prospect of an International Federation with regard to oil matters, and there was not the slightest doubt that the subject of standardisation should be taken into account by it, because it would be utterly futile for an Association such as the Institution to begin a programme so enormous as was involved in the standardisation of all aspects of the oil question without taking into consideration the very large amount of work that had been done and was being done in America. As the members were aware, he was always very keen to correlate pure science with its application, when it was possible to do so, and in that connection he desired to refer to one or two points raised in the paper. It was interesting to note on the first page of the paper that, in reference to a paper by Mr. Deeley on "Oiliness and Lubrication," it was said: "The view expressed by the author is that the oil, or some constituent of the oil, enters into physico-chemical union with the comparatively rigid metallic surface." He would like to know what other union it could enter into that was not either physical or chemical. Mr. Allen suggested that the property of oiliness depended upon the chemical forces called into play between the active part of the oil molecule and the solid

surface of the bearing. It would be noticed that Mr. Allen was more specific. He did not say it was "physico-chemical" but that it was chemical, and so far that was a stage further in advanced knowledge. Mr. Hardy dealt with the subject as one expected he would do. The fact was that Langmuir and Hardy's work had demonstrated that when an excessively thin film of oil was formed the molecular groups were orientated in a specific direction, particularly on the surface of water, which had been definitely proved by Langmuir. On the surface of steel or of metal it was highly probable that the oil molecule was orientated in such a way that some residual affinity or valency, or as modern theory would say, a stray or residual electro-magnetic field on the surface of the metal, was so orientated that the oil could sit on it in a certain direction. It was impossible with the means at their disposal at present to say whether that oil was really chemically combined in the sense in which the word was ordinarily used, but it was possible to prove the point in very analogous cases. He desired to introduce to the notice of the members a case which at first sight seemed as far removed from lubrication as anything could be, in the hope that it would show the value of work in one direction in its bearing on matters in another direction. If a mixture of 100 grammes of china clay and 1½ grammes of caustic soda were put in pure water, the whole of the caustic soda would stick on to the clay surface, and if the clay was filtered off the water would be found to contain free caustic soda. The clay might be treated with distilled water for days and weeks, but no caustic soda would be obtained from it. If, however, it was subjected to an electric current it would be found that at exactly 1·68 volts caustic soda came back into the water, 1·68 volts being the identical voltage at which caustic soda was chemically decomposed when it was present in water. In other words, there seemed to be little doubt that the caustic soda was so stuck on to the surface of the china clay that it was held there with such force that nothing but the utilisation of an electric current which would be equal to splitting common salt or caustic soda into sodium would suffice to remove it. If a corresponding experiment could be carried out in that electro-chemical manner with oil it might be possible definitely to settle the point whether the oil was actually chemically held on, a point of great importance, because the moment it was possible definitely to say what laws underlay the property of the adhesion of oil to a surface they were on the straight road to proper methods and proper definitions, and incidentally to robbing the commercial gentlemen who went round in great numbers of their opportunity of saying in fluent language,

with little science, why their oil was so much better than everybody else's. In one portion of the paper the author spoke of castor oil mixing with other mineral oils when it was used in the polymerised form. He would like to know whether polymerised castor oil had the same properties and lubricating powers as unpolymerised castor oil. His own recollection of polymerised castor oil was that it looked like a very good substitute for indiarubber; it might have been polymerised too far. In dealing with the question of flash point the author had made no reference to the importance of the presence of moisture, which had been very ably dealt with by Mr. Philip in his paper. With regard to surface tension, it was never sufficiently pointed out that surface tension as determined by the ordinary methods was a surface tension between oil and air. That might have no bearing or very little bearing on what they wanted to know, namely, the surface tension between the oil and the metal. As showing how enormously different those were, he suggested that the following experiment should be tried, namely, on a freshly planed cast iron surface there should be placed close together one drop of sperm oil and one drop of pure mineral oil, having the same viscosity. The enormous difference in their behaviour would be immediately noticed. The sperm oil would spread over a wide area with very great rapidity, whereas the mineral oil would spread over a much less area and much more slowly. Until some means were found of measuring the surface tension of the oil against the metal, he did not think any other work was of very great value; certainly his own experiments went to show that the method of dropping oil in air was worse than useless. The difficulties of obtaining concordant results were very great. The author further stated in his paper: "Attention is drawn to the necessity for preventing the admixture of lubricating oil with fuel oil." That was a problem which came very much into play in dealing with the question of lubricating oils for the crank cases of engines, and it introduced the necessity for special tests. That was one of the difficulties the members were up against, that, according to the use to which the oil was to be put, an entirely different range of comparative tests would have to be entered into. A series of tests which would settle whether an oil was good for insulation in a transformer would be of very little value in settling whether the same oil would be good as a thin spindle oil or for some other direct lubrication purpose. The flash point was of particularly little value except in regard to the storage question. A very little light oil might be added to a heavy lubricating oil and a flash point be obtained which conveyed very little information indeed

about the oil itself. With regard to the question of the volatility of oils, the author had dealt at some length with the methods for carrying out the Archbutt-Deeley test. He desired to point out that Archbutt and Deeley found very little difference whether they were passing air or steam over the oil in order to get the loss, and yet he thought all the members knew that when it came to a question of the distillation of an oil the effect of steam and air was vastly different. He was told that in Germany certain of the works distilling large quantities of oil had found that distillation carried out in an atmosphere of nitrogen yielded far superior products, and that the rapidity of the transfer of the oil from the still to the condenser was very much greater than when either air or steam was used, and a number of firms making oxygen for commercial purposes were using the nitrogen, which would otherwise be a waste product, for the distillation of oil. That he thought was a matter which was worth some slight consideration. He desired to show some curves dealing with the question of heat loss, because the author stated that the American authorities had claimed that there was very little value in that test. On the contrary, for cylinder lubrication purposes, for the crank cases of internal-combustion engines, he knew of no test which was of such great value. It might be true that it was difficult to get concordant results as between one person and another with open dishes and so on; nevertheless, if the work was rationally done and was always carried out in the same way, it gave figures that were of the greatest value. There was a distinct connection in the long run, when hundreds of tests were done, between the heat loss and the flash-point, and secondly in the endeavour to work out a standard method for heat loss, which was badly required, the question of the time and the temperature must be settled.

The diagrams shown are contained in a paper on "Engine Lubricating Oils," by Ormandy & Lester. Proceedings Inst. Automobile Engineers, vol. 8, pp. 371.

The diagrams pointed to the necessity for an investigation of the whole subject of the shape of a vapour tension curve. He believed the members of the Institution were fully aware of the necessity for standardisation, and he hoped they were also aware of the fact that the subject was so enormous that it was not one which the Institution could tackle as a whole, and that the members could only be assisted in a general manner in the directions the President had indicated.

Mr. E. H. Cunningham Craig said he only desired to deal with one point raised in the paper, namely, the subject of oiliness.

He thought everybody knew what oiliness was, but he gathered from what the author had said that they did not. He thought he could perhaps add a little information on the subject, if it was not already known to everybody. Dr. Ormandy had given some instances, for instance, the adsorption of caustic soda and so on, which were all part of the same subject. The whole question was one of surface energy, which had been proved to be electrical. Reference was frequently made to the various ways in which certain lubricating oils behaved, but people did not always stop to consider what that oil was. The oil was not a simple thing. The crude oil was a colloidal solution or sol containing a great number of different substances, probably a great many different "disperse phases," each of which had its own surface energy. In a lubricating oil many of the simpler compounds had been removed, but a great number of the more complex compounds remained, each with its own particular surface energy. When a surface was brought against an oil of that particular kind, the first thing that happened was a concentration along the solid surface of the particular disperse phase which had a surface energy nearest to that of the solid surface, and then there was a selective concentration of other disperse phases one over the other, until an absolutely perfect arrangement was obtained which prevented any kind of internal friction. That was what oiliness was. This also explains why introducing some other matter, such as an acid or certain other substances, simply by adding another disperse phase to the particular sol, would enable more concentrations of the various disperse phases to take place towards the surface, and would thus naturally increase the efficiency of the lubrication. Thus lubrication, oiliness and viscosity all depend on the presence of disperse phases, which become concentrated in ultra microscopic films parallel to surfaces and thus practically eliminate friction.

All these phenomena are part of one great subject and cannot be considered separately.

Dr. Dunstan said he desired in the first place to draw attention to the author's reference to unsaturation as being one of the fundamental causes of the property of lubrication. He thought it was two years since Dr. Thole and himself discussed that subject before the Institution. He believed that unsaturated hydrocarbons were first recognised by Marcusson, Nastyukov, Kheritchkov and Engler. When it was borne in mind that practically every abnormality in chemical behaviour could be traced to unsaturation or the presence of residual affinity, it was rather suggestive that high-boiling mineral oils, which were always more or less unsaturated, should possess

the particular property of lubricating power. He was inclined to agree with Mr. Cunningham Craig that that lubricating power was somewhat intimately connected with colloidal nature. Whether the colloidal nature was due to the unsaturation, or whether both were due to some deeper underlying chemical prime cause, he could not say. It was not much use merely stating that the property under discussion was due to chemical, magnetic, electrical or any other cause; the plain fact was that they did not know. So far as the colloidal structure was concerned, Mr. Cunningham Craig would remember that it had been definitely shown that the ordinary lubricating oil of commerce was a colloid. He noticed it was stated in the paper that: "Under certain specified conditions of lubrication W. B. Hardy finds that the lubricating power of the paraffinoid hydrocarbons increases with increasing molecular weight, that their acid derivatives lubricate better, and the alcoholic derivatives better still, the best lubricants being substances containing both carboxyl and hydroxyl groups," i.e. if hydroxyl or carboxyl were substituted for hydrogen an increased lubricating power was obtained. That was the very same direction in which the viscosity increased, so that the lubricating power and the viscosity were probably very deeply and intimately connected. That was particularly the case if there was a conjugation of such a group as hydroxyl and carboxyl with a double bond as is the case in castor oil. That made it pretty clear that (excluding mechanical tests) the viscosity was at the present moment the only practical laboratory test of lubricating power. As to what oiliness was they did not know and it was not much use theorising about it. He thought the author might have emphasised, in connection with the refining of lubricating oil, that it was possible to refine lubricating oil too much, and that the more vigorously one refined in the endeavour to get a better colour the greater risk there was of losing valuable components. The author had mentioned two tests, namely, the gumming test and the iodine value. So far as gumming tests were concerned, he thought most oil chemists used some variation of the following method: A certain weight of oil was exposed on a certain definite surface for a known number of hours at a predetermined temperature; at the end of that time the residue was treated with petroleum ether, allowed to stand, and the insoluble portion was filtered off and weighed. He knew quite a number of fellow chemists who made use of some method of that sort, and it gave quite reasonably concordant results. Some time ago he was interested in iodine values as a possible method of dealing with the problem, but it was found that even after rigorous treatment with

oleum there remained a distinct iodine value, and, moreover, for any given lubricating oil the iodine value was a function, firstly, of the concentration of Wij's solution, and secondly, of time.

Mr. Arnold Philip congratulated the author on what he thought would prove a very useful summary of a subject which covered an enormous amount of ground. Owing to the amount of space available in the Journal, and perhaps owing to the limited amount of time at his disposal, it had naturally not been possible for the author to deal very fully with most of the subjects touched on. He did not wish to attempt to criticise a paper dealing with such a very large range of subjects, but he desired to make one or two remarks on the question of lubrication. Oiliness had been defined in scientific terms by Mr. Cunningham Craig. Many people had defined it in different ways, but it appeared to him that, however it was defined, people would never accept any definition, or any physical measurement or any chemical measurement as satisfactorily fixing the character of a lubricant. Only the behaviour of an oil in a mechanical oil testing machine or on actual running machinery could be regarded as deciding its quality. It was impossible for anyone to sit down at a desk and by any calculations show that a liquid was a good lubricant. No knowledge of the physical or chemical properties of an oil, except in so far as they showed it resembled or was identical with some material which had already been found to be a good lubricant by practical tests, could definitely decide its lubricating value. The question might be asked of him whether a particular substance could be stated to be a good lubricant or not from the results of physical and chemical tests, and his reply would be in the affirmative if he could see by the results of the physical and chemical tests that it was, say, an olive oil, because he already knew that this oil was an excellent lubricant, but the knowledge that it was so had been obtained by making real lubricating tests in the past. It was only practical lubricating tests that would ever be used as a basis for deciding whether an oil was a good lubricant and had oiliness. Oiliness really meant that an oil was a good lubricant; in fact, a definition of oiliness might well be that it was the lubricating value of an oil.

An interesting point had been raised as to the connection between the viscosity of an oil and its lubricating value. In his experience the higher the viscosity of an oil the worse it was as a lubricant, i.e. the thicker the oil the worse its lubricating value, and subject to one proviso one would prefer to have an oil that had a very low viscosity. The necessity of this proviso was due to the fact that if an oil was put in a bearing it might be squeezed out by high

pressure or shaken out by vibration. It was therefore necessary for the lubricant to have a viscosity so great that it would withstand the pressure between the bearing surfaces and the vibration without being squeezed or shaken out. It was thus necessary to have a limiting high viscosity, but after that, within proper safe limits, the lower the viscosity the better the oil was as a lubricant, that is if it was used on surfaces running at moderately high speeds. He thought there was a certain amount of value in the determination of the flash point of a lubricating oil, although it was not very great. It might show the origin of the oil. For instance, he thought it was possible very often to tell the difference between an extracted seed oil and one which had been obtained by crushing, because the extractive solvents were, very often at any rate, solvents which had low flash points and traces of these were sometimes left in and caused the extracted oil to have rather a low flash point. As a matter of fact, as non-inflammable solvents were now often used, the subject had not the importance that it formerly had.

It had been stated in the past that lubricating oils used in steam cylinders with superheated steam had caused explosions when their flash points had been too low. The actual basis for this statement he did not know, but in any case oils used for such purposes should in general have high flash points as this meant that their volatility was low, and such oils would not be carried away so rapidly by the steam.

Dr. Blackler thought that an outsider who knew nothing about lubrication would, after listening to the paper and discussion, come to the conclusion that no one knew anything regarding the real factors which govern the lubricating properties of petroleum oils. One only knew what the oils would do under working conditions, and the relative value of saturated and unsaturated bodies under various conditions were not yet appreciated. He held no brief for any side with regard to lubrication, but it had been his province during the last three or four years to have some dealings with lubricating oils in the preparation of medicinal products, and in that connection he had treated oils from all parts of the world, with the object of obtaining medicinal petroleum. The original oils used varied considerably in gravity and viscosity, but the physical constants of the resulting saturated bodies bore no relationship to the physical constants of the oil. Lubricating oils with high gravities at times, gave saturated products of high gravity and low viscosity, while on the other hand an original oil from another district of the same gravity would give a medicinal product of low gravity and high viscosity. In order to obtain medicinal oil of

uniform physical constants, lubricating oils from various sources had to be blended and used as the raw product in order to obtain this result. In passing, he referred to certain Californian oils mentioned by Dr. Dunstan that had been treated with oleum to remove the unsaturated bodies and stated that, unless oils so treated had been carefully filtered through some medium such as floridine or bauxite that they would not be pure saturated bodies, but contaminated with from 3–5 per cent. of curious sulphonated bodies which could not be removed by any chemical method.

It seemed evident that the unsaturated and the saturated bodies in lubricating oil each played an important part in the problem of lubrication, and the conditions under which it was used affected the relative value of the two constituents. He believed that, if one took pure medicinal oils with various viscosities and added to those saturated bodies definite proportions of unsaturated bodies and correlated the whole of the tests, one would begin to appreciate more definitely which constituent of the mixture played the important part in the lubrication test under review. A series of tests made just before Dr. Dunstan read his last paper before the Institution showed that the viscosities of the unsaturated bodies decreased very rapidly with increasing temperature, whereas those of the saturated bodies decreased very much more slowly. He realised that a great amount of research work was required to be done in the direction intimated, and if any member of the Institution would like him to look out a number of samples of oil for the purpose of experiment, he would be happy to place them at his disposal, provided the samples had not already been destroyed.

Mr. Bowrey supported the appeal for due regard to American and foreign work in standardising tests of oil. Those who had had anything to do with American refiners and merchants were fully aware of the difficulties occasioned by differences between the English and the American systems. Viscosities in particular were difficult to translate from the English to the American system on account of the use of different standard temperatures, and we should do well to guard against the development of new tests on divergent lines. The emulsification test was of recent introduction and two methods of carrying out that test had attracted attention, namely, Mr. Philip's method in this country and the American Bureau of Standards' method, the latter of which was more recent in date than Mr. Philip's. In fairness he thought it should be said that the Bureau of Standards' method possessed some advantages. It was a test which could be carried out in as many minutes as Mr. Philip's test required hours; it could be done with much less

expensive apparatus; it required 20 c.c.'s of oil whereas Mr. Philip's test required 500 c.c.'s, and it yielded consistent numerical results nearly, if not quite, as informative as Mr. Philip's. The author of the Bureau of Standards' test had benefited by Mr. Philip's original work, and it was necessary to set against our natural preference for a method invented at home the fact that the Bureau of Standards' method had gained acceptance in the U.S.A. to an extent which neither had yet done here. It was of supreme importance that the two countries should not adopt different methods, and he thought that consideration should over-ride any insular sentiment.

Mr. Evans thought the members were apt to attach too much importance to the abstruse question of oiliness. In the selection of a lubricant one was not usually so much concerned with the coefficient of friction. That was certainly important, but there were other considerations which sometimes outweighed it. Quite recently a question arose in connection with a committee in which he was interested with regard to aero engines, and he was then told that the coefficient of friction of the lubricant was of secondary importance to the question of carbonisation and other matters. He thought one ought to think of the value of the lubricant as the first consideration in the selection of an oil and not of its lubricating value. With reference to the point raised on page 329 of the paper with regard to the substitution of mineral oils for castor oil in aero engines, he presumed that did not refer to rotary engines, but to stationary engines and to American practice and not to British practice. With regard to polymerised castor oil to which Dr. Ormandy had referred, polymerised castor oil was certainly not polymerised to the degree which he mentioned; it was only slightly treated. As a matter of fact that type of oil was not used very much. The statement was made on page 331: "When mineral oils are to be used in the preparation of compound oils or greases, they may, provided the flash point is not low, be of comparatively low gravity." He would be glad if the author would indicate a little more clearly what he referred to in that connection. The further statement was made on page 333 that "all oils approximate in viscosity at 400° to 500° F." He ventured to suggest that that depended upon the form of viscometer that was used. With reference to Dr. Ormandy's remarks that it would be of advantage if some work could be done on the question of vapour tension of oils, he believed that work was already in hand.

Dr. Thole emphasised the high importance of the oxidation or gumming test especially in connection with lubricating oils used

in internal-combustion engines. This test is most readily carried out by exposing a weighed amount (say 1 gramme) of the oil in a thin film to the action of hot air for a definite time, extracting the residue with light petroleum and weighing the insoluble matter. Such a test is much more discriminatory than many other tests commonly applied to lubricating oils. The speaker mentioned two well-known oils which are practically identical as regards colour, specific gravity, viscosity and flash point; the amounts of insoluble, gummy oxidation product resulting from the above-mentioned test under identical conditions were respectively 0·4 per cent. and 12 per cent. well justifying the relative reputations these oils possess.

Mr. Arnold Philip doubted if it would ever be possible to decide from the physical and chemical constants of an oil as to its lubricating value, and considered practical results on a machine or engine the only arbiter. This attitude seems unjustifiably pessimistic; in the speaker's opinion it will not be beyond the possibilities of oil research to ascertain, not only the necessary qualities of a good lubricant for any specific purpose, but also (the more difficult problem) the extent to which these qualities overlap and the degree to which they consequently neutralise or augment each other. The testing machine measures the resultant effect of a variety of influences (viscosity, "oiliness," surface tension, temperature, coefficient and probably others). When we know more about the causes it should not be an impossible matter to calculate this effect.

The President announced that the author had been kind enough to say that he would send in his reply in writing, so that it only remained for him to declare the meeting at an end.

The proceedings then terminated.

Mr. Robertshaw communicated the following reply to the discussion:—

Sir Frederick Black's reference to the possibility of the organisation of an International Conference for the discussion of petroleum problems is of great interest to us. Such a conference would almost certainly bring to light numerous cases of lubrication problems solved during the war by the application of new methods of examination, chemical, physical and practical.

I fully concur with Dr. Ormandy's remarks about taking into consideration the work done in America on the methods of examination of oils. A few references are given in the bibliography to some of this work. Reference to the Proceedings of the American Society for Testing Materials will prove of great interest when considerations of methods of test are in question. For example the Volume XVIII (1918) contains accounts of work by Herschel

on the Standardisation of the Saybolt Viscometer, Bingham on Viscosity Determinations and Conradson on Oils for Internal-Combustion Engines and on Evaporation Tests. Dr. Ormandy's remarks on the possibility of saying definitely what laws underlie the property of adhesion of oil to a surface are of great importance. Whilst we are at present faced with the problem of standardisation of the tests used, we may, for the future, look with confidence to that correlation of pure science to its application, of which Dr. Ormandy speaks, for the discovery of new tests founded upon a surer knowledge or for the alteration of old tests in the light of new experience. The china clay experiment described is an excellent example of the benefit which may be derived from the application of the results of research to the practical problem of the examination of lubricating oils.

The problem of dealing with the question of dilution of lubricating oils in the crank-cases of engines is one which is requiring an ever increasing amount of attention. As the fuel alters in composition this liability to dilution tends to vary. The question has been recently dealt with by the Bureau of Standards.

In view of the general uncertainty as to the value of the evaporation tests as usually performed, Dr. Ormandy's communication of a type of test designed to meet special conditions is of particular value and interest, and I fully agree with his views as to the necessity for settling the temperature and time for evaporation tests. These factors depend upon, and vary according to, the use for which the oil is intended.

The possibility of over-refining lubricating oil, referred to by Dr. Dunstan, was mentioned in the discussion on the paper by Dunstan and Thole, and I certainly agree that the importance of the matter should be emphasised. In the paper referred to, clear evidence was given that over-refining with H_2SO_4 would lead to loss of material having valuable lubricating properties. Probably everyone concerned with lubricants has had practical proof of the fact that a light-coloured lubricant is not necessarily a good one, and it would be well for refiners generally, from the point of view of economy alone, to give earnest consideration to the point raised by Dr. Dunstan.

Mr. Philip's paper on "Some Laboratory Tests on Mineral Oils" is an excellent illustration of the necessity for dealing with each well-known test used for oils in a comprehensive and detailed manner. The tests used for lubricating oils are so many, and vary so widely, according to requirements, that similar treatment would require several papers each dealing with two or three tests.

The flash point of a normal lubricating oil is usually well above the temperature at which the water is completely driven off. I do not think that the presence of water in the original oil has so important an effect on the flash point determination as it has in the case of such oils as those dealt with in Mr. Philip's paper.

The following figures may serve to illustrate this :—

	Oil used : Good grade Engine Oil.		
Closed Flash Point.	Dry oil ..	193° C. ..	193° C.
	+ ·5% H_2O ..	194° C. ..	193° C.
	+1·0% H_2O ..	193° C. ..	—

Great difficulty was found in preventing overflow in the case of the 1 per cent. water experiment. Two tests overflowed and gave slightly lower figures.

Mr. Philip's experience confirms the necessity for the correlation of the results of physical and chemical tests of lubricating oils with those of practical trials.

Mr. Evans's observation on the tests required for an oil to be used on aero engines is in agreement with the information given by Conradson in 1918 in the paper on the Lubrication of Internal-Combustion Engines. In that paper the carbonisation test is referred to and the conditions of carbon formation in the cylinder are described.

The expression gravity to which Mr. Evans referred, is intended to indicate different oils from the same crude where oils of lower gravity may usually be expected to have lower viscosity. The question of the substitution of mineral oil for castor oil for use in aeroplane engines, refers to stationary engines, although I understand that a certain amount of successful experimental work has been done using mineral oil on rotary engines.

I agree with Dr. Thole's insistence on the importance of research into the factors which affect the lubricating properties of oils. When these factors are known, some of the purely empirical methods now in use may be dispensed with, and many of the problems which are associated with standardisation may be solved. Dr. Blackler's remarks about the difference between the viscosity temperature curves of saturated and unsaturated compounds, agree with the observations already made that probably the best mineral lubricating oil is obtained with the normal mixture of saturated and unsaturated compounds.

Dr. Thole's remarks emphasize very clearly the importance of taking into consideration every property of an oil under examination. In the present state of our knowledge it is only possible in many cases to make comparisons with known standards. Every

test, therefore, which indicates in any way the probable behaviour of a lubricant in practice is of importance.

In conclusion, I desire to express my thanks to the British Dyestuffs Corporation Blackley, Ltd., for permission to present this paper, and to Miss G. Robertshaw for her work on the bibliography.

Forty-Seventh General Meeting.

This Meeting was held at the House of the Royal Society of Arts, John Street, Adelphi, W.C. 2, on Tuesday, 18th May, 1920, Sir Frederick W. Black, K.C.B. (President), occupying the Chair.

The Members of Council present were Prof. J. S. S. Brame, Mr. E. H. Cunningham Craig, Dr. A. E. Dunstan, and Messrs. Arthur W. Eastlake, and T. C. Palmer.

A message of regret for unavoidable absence was received from Dr. F. Mollwo Perkin.

The Hon. Secretary (Mr. Arthur W. Eastlake), announced that the following gentlemen had been elected :—

As *Members :*—Henry Samuel Denny, John Gillespie, Albert Jeffreys, William Rogers, James Liddell Rossini, and John Clark Templeton (transference from Associate Member).

As *Associate Members :*—William Allan, William English, Andrew Pollock Faickney, Norman Victor Sydney Knibbs, Stanley John Nathan, Justice Thomas Parker, and William Leopold Samson.

As *Students :*—Ralph Peter Bolton, Andrew Menzies, and Bernard Ian Richardson.

As an *Associate :*—Reginald Herman Young.

A Meeting of the Institution of Petroleum Technologists was held at the Royal Society of Arts on Tuesday, 18th May, 1920, Sir Frederick Black, K.C.B., President, in the Chair.

The President announced that the present meeting was the last of the Session. He thought the members were to be congratulated on a very successful year, the interest in the proceedings of the Institution having been kept up to the very last meeting. The Council was at the present time very actively engaged in preparing the list of papers for the next Session. Only three papers had already been selected, so that there was still room for contributions from the members, and the Council would be very glad to hear from anyone who wished to give a paper during the next Session. As he had mentioned on a previous occasion, two extra meetings would be held during the next Session especially

for the benefit of junior members. Those two meetings would be additional to the ordinary eight meetings of the Institution.

He regretted to announce that Mr. Stirling, the author of the paper that was to be read that evening, was unable to be present at the meeting, but Mr. George Howell had very kindly volunteered to present the paper in Mr. Stirling's absence.

The following paper was then read by Mr. Howell in the absence of the author :—

"The Air-Lift System of Raising Oil."

By R. Stirling, *Member*.

It is not proposed to treat of the air-lift as a system of pumping, but only of its application to the pumping of oil wells, and, incidentally, of the modifications in the apparatus, which have been designed to meet the special conditions met with in the wells. The air-lift system as differentiated from all other systems of raising liquids by means of compressed air, is that in which the action depends solely on the aeration of the discharge column of liquid. The weight of this column must, in order to obtain the discharge, be lighter than the column of liquid in the well, so that by no possibility can any additional pressure be put on the strata in the well. Failure to realise this fact has given rise to one of the chief arguments against the use of the air-lift in oil wells, that the compressed air will drive the oil back into the oil sands, or into other porous strata.

The air-lift, properly applied, is the most advantageous method of raising the oil from all wells yielding sufficient liquid for the continuous working of an apparatus of the smallest practicable capacity. It is particularly advantageous for wells which have ceased to flow naturally, and either flow intermittently or not at all, because by the air-lift much larger yields can be obtained than by any other system of pumping. Any gas present with the oil assists the air-lift by reducing the quantity of air required, and the energy of the gas now wasted is thus utilised. Where the oil is found in loose sands which enter the well with the oil, the air-lift is the only practicable means of raising the sand with the oil, and so keeping the well always clear to the bottom, and thereby securing the maximum yield from the well.

The use of screens to prevent the sand entering the well is worse than useless, because, unlike water, oil on account of its viscosity will not wash out the mud and fine sand, which packs outside the screen, and becomes impermeable to the oil.

The sand cannot be extracted by the ordinary oil well pump, with the working of which it moreover so seriously interferes that the pump must be placed some distance above the bottom of the well, so that most of the sand may settle out of the oil before reaching the pump. This sand gradually accumulates and prevents the free influx of oil to the well, so that the yield steadily diminishes, until the minimum payable yield is reached, when the pump must be withdrawn and the sand removed by sand pump, causing a further loss of production while the operation is being carried out, besides the cost of the work. Moreover the ordinary oil well pump is a much less efficient machine than the improved air-lift apparatus. The only other method besides the air-lift of raising the sand with the oil, and so keeping the well clear is that of baling as developed in Baku, but, besides being too cumbrous and uneconomical to bear comparison, this method necessitates wells of large diameter, if even a moderate production is to be obtained. In 1900 careful inquiry failed to discover that the air-lift was being used for pumping oil wells in the United States, but compressed air was being used in Corsicana, Texas, for periodically blowing out the oil, as it accumulated in the wells. This and similar displacement systems, besides being uneconomical, had serious disadvantages, and the results following their use did much to discourage the introduction of compressed air for pumping oil wells. The theoretical advantages to be obtained from the use of the air-lift for pumping the wells in Baku where the loose sand trouble prevails, were so apparent that a systematic application of the system was started in 1901. In that year the air-lift system of pumping was successfully applied to several wells. The first well, No. 24 Bibi-Eibat of the Russian Petroleum and Liquid Fuel Co., was 1,358 ft. deep, and the oil stood at 600 ft. from the surface. The daily production by baling had averaged 1,200 poods during the previous year, but by air-lift the yield of oil averaged 12,000 poods per day during 6 months.

The oil was taken from below the casing shoe, but the compressed air was introduced higher up, the working air pressure ranging from 160 to 110 lbs. per sq. in., during the period. The second application was in well No. 41, on plot No. 173, at Saboonchi of the Baku Russian Petroleum Co., depth 1,414 ft. and liquid level 595 ft. from the surface. This well had flowed, but the casing having been damaged only a small production was obtainable by baling. By air-lift it yielded 7/8,000 poods per day, and was reported to be still producing in June, 1903.

Several other wells were equipped with the air-lift before the end

of the year, and gave equally satisfactory results. Some of the results obtained are given in the Appendix, extracted from an Editorial, which appeared in the official Technical Oil Journal of Baku of 5th June, 1903.

Altogether over 50 wells were experimented with during the three years 1901/4, all damaged wells or flooded by water, and many interesting facts were revealed. It was clearly proved that there need be no fear that the air-lift intelligently applied will damage a good well, although it may disclose and even aggravate defects in a defective well. It has been objected that in obtaining a greater production from a well the level of the liquid in the casing will be lowered to such an extent that the casing might collapse, but it is necessary to lower the level to induce a greater influx of oil, and if the casing be defective it may collapse. Unless, however, the casing be capable of withstanding the greater pressure to which it must be subjected by the lowering of the level of the liquid, there can be no hope of getting the increased production by any means. Moreover the level of the liquid in the well will fall in any case sooner or later, as the oil becomes exhausted, and eventually the casing will be called upon to withstand the greater pressure. As a matter of fact the casing was not collapsed or damaged in any of the wells tested, although the liquid level was lowered in some cases several hundreds of feet. A favourite argument against the use of the air-lift is that the inflow of the water is induced thereby. Of course by lowering the level of the liquid column, pressure is removed from the liquid bearing strata, and the liquids they contain, whether water or oil, if they have access to the interior of the casing, will enter in increased quantities. If both water and oil have unrestricted entrance to the casing, as when both come from a flooded oil stratum, both will enter in the same proportion as before, and the greater production of liquid obtained by the air-lift will carry a similar proportion of oil to that in the lesser production obtained by other means. An illustration of this was given when two adjoining flooded wells were pumped by air-lift. The oil in the liquid was 2 per cent., when 5,000 poods per day were raised by baling from one well, and when 20,000 poods per day were raised from each well by air-lift, as also when 40,000 poods per day were raised from one of the wells.

If the entrance of one of the liquids is restricted, as when one enters through a defective joint or hole in the casing, then the proportion of the liquid, the entrance of which is unrestricted, will increase in much greater proportion, and if this be oil the results may be quite satisfactory without the expense of shutting off the

water. As illustration of the above, one well with damaged casing yielded by baling 1,500 poods of oil and 300 poods of water per day, but by air-lift 14,500 poods of oil and only 500 poods of water. When the air-lift was applied to another well the percentage of water increased greatly, but the quantity of oil was only slightly greater. It was diagnosed that the water entered from below the casing, and the oil from a higher level through a defect in the casing. A packer was placed in the casing near the bottom of the well with the result that almost pure oil was obtained, in quantity several times greater than before, the level of the liquid in the casing being lowered by several hundreds of feet. In another case the level of the liquid having been lowered by the air-lift, water could be heard cascading into the well. A packer was placed in the casing below the level at which the water entered, and the well was pumped from below the casing shoe, with the result that it shortly began to flow and continued producing 8/15,000 poods of oil per day. Only one disadvantage has to be recorded against the use of the air-lift in that with very heavy viscous oils, if over 5 per cent. and under 20 per cent. of water be present with the oil, an emulsion may be formed from which it is difficult to separate the water. Wells yielding oil with less than 5 per cent. of water were pumped without this trouble, and in a well with 10/15 per cent. of water the difficulty was overcome by running into the well an additional 20 per cent. of water. No serious emulsion was then formed, and the discharge was so much facilitated and increased, by the addition of the water that the quantity of oil obtained was greater, without any extra expenditure of air to raise the added water. When emulsion was formed it could generally be easily broken up by mixing with a lighter oil from a neighbouring well. It was at first feared that the air might carry off some of the lighter constituents of the oil, but this has been proved, both in Baku and in Trinidad, to be groundless. The refineries reported that if anything the oil raised by air-lift retained a greater proportion of the lighter fractions, probably owing to the slight refrigerating effect of the expanding air.

The question will at once occur to most minds why with such satisfactory results the air-lift pumping of oil wells has since 1904 made little or no progress in Baku, and in other fields has chiefly been used to pump wells in water flooded areas, merely because by this means a larger quantity of liquid can be pumped from a bore-hole of restricted diameter than by any other. The answer must be that the disturbances in Baku during the Japanese war dispersed the technical staff who had been engaged in solving the various

problems, before the system had become established in general use. The apparent simplicity and ease of demonstration of the air-lift principle led engineers to take for granted that the design of an efficient apparatus was equally simple. Unsuitable designs were tried, unexpected and apparently inexplicable results were obtained, and the causes were confused with conditions pertaining to the particular wells. This may appear surprising, but a similar example is that of the centrifugal pump, the principle of which is so easily demonstrated. It was in use for hundreds, perhaps thousands of years for low lifts before its action was scientifically studied, and in consequence its efficiency improved so that to-day it is efficient for very high lifts. The steam turbine is another, and more recent example.

In recent years the serious difficulties with the loose sands in some of the oil fields of Trinidad have proved such a handicap to their development that it was decided to use the experience gained in Baku to overcome them. The conditions met in the wells are very similar, although the application of the remedies are rendered much simpler on account of the use of screwed casing, and the rotary system of drilling being already established. These make it feasible to control the wells during the eruptive stages, when irretrievable damage is often done to a well, and systematically to apply the air-lift as the general system of pumping the wells. Already the success of the system has been clearly demonstrated, and the conditions prevailing in the wells discovered and met. At the same time the unsuitability of some of the standard designs of oil well material, and unexpected conditions have been revealed. In one of the first wells experimented with, the air-lift ceased to work properly, and on withdrawing the drill stem it was found to be perforated in various places corresponding to the standard pitch of the perforations in the casing. This showed that the oil and the sand from an upper oil sand were, when the liquid level was lowered, being forced with the gas through the perforations with such velocity as to create a sand blast. The lesson learnt was that, if perforated casing was to be used to drain these sands, the perforations in place of being $\frac{1}{2}$ in. diameter, 6 in. pitch, should be either of larger diameter or much closer pitch so as to give free passage to the oil. The Appendix gives some of the results obtained during the experimental stage of the introduction of the system. Many more discoveries have to be made before the conditions are fully understood, but experience has taught that they have only to be discovered to be satisfactorily met. The scientific study of the conditions peculiar to any oil field or individual well, besides being

most interesting, is essential, not merely for the proper application of the air-lift pump, but also for deciding the most suitable methods of drilling, casing, shutting off water, and production. It has too often happened that methods have been adopted by rule of thumb without due regard to the special conditions. Oil well operators have been too apt to be content with a payable production from a well, without considering if, and how, the daily production, and the total production of a well might be increased.

As an instance of this take the example given of Well No. 24 in Baku. Everyone was satisfied with the production of 1,200 poods per day, and in fact the well which had been intended to tap a lower oil source was stopped at the higher sand, because the production was considered so satisfactory. It was only with serious misgivings that it was handed over for the air-lift experiment, yet it was found capable of yielding 14,500 poods per day, and actually yielded over 2,000,000 poods in six months, as compared with some 400,000 poods in the previous 12 months. Hundreds of wells in the field would have given equally good results, as was proved by the experiments on damaged wells, and wells giving unremunerative yield. It may be accepted almost as an axiom that every well, which to-day cannot be pumped dry by the pumps in use, could be made to give a greater yield, if pumped by air-lift, lowering the liquid level, and keeping the well constantly clear to the bottom. Perhaps the only exception might be, when the oil enters the well only from a higher sand, or when pumping a larger quantity an unmanagable quantity of sand is brought in, or a quantity which might cause a dangerous disturbance of the strata.

The addition to the air-lift apparatus of a valve at the bottom of the discharge pipe is the vital improvement, which makes it applicable to wells containing loose sand, without incurring the serious trouble of frequent choking of the pipes by sand.

The necessity for such a valve at the bottom of the well was clearly indicated by the experiments carried out in Baku, but the idea was only crystallized later, and the present design evolved and described in the patent granted in 1917 (British patent No. 117,567 and U.S.A. No. 1,279,783). This foot valve, which can be fitted to the rotary system drill stem enables a well to be drilled into an oil sand with gas under high pressure, so that an unrestricted flow with the consequent disturbance of the strata in the vicinity of the borehole can be prevented, and the flow when permitted, which is now generally interrupted by the choking of the pipes with sand, can be maintained uninterruptedly by the application of compressed

air with the air-lift apparatus. The general experience in Baku and Trinidad has been that, having penetrated the high pressure oil sand, after one or more violent eruptions and the ejection of a large quantity of sand the casing became damaged or the well ceased to produce oil, and was considered to have become exhausted. What had really happened, however, was that the removal of the sand had allowed the capping material, generally a clay, to fall in and dam off the oil from the well. If the flow be restricted from the start much less sand will be removed, and the steady flow will encourage the formation of channels in the sand draining a large area around the well.

Other additions, which make practicable the pumping of water and oil wells in groups, are the air regulator and meter valve, which not only distributes the air in proper quantity to each well, but at the same time indicates the quantity. Also the supplementary, or starting, air nozzle, which obviates maintaining a high and wasteful pressure in the air main to start a well, the liquid level in which rises when standing, far above the level it maintains when pumping is in progress. An important improvement in the air-lift apparatus especially adapted to the oil wells is a footpiece or air nozzle designed to obtain a thorough mixture of the air with the liquid, without the excessive loss of air by slippage, which is known to occur when gas is present with the oil.

The air-lift apparatus as designed with the above-mentioned additions and improvements, is so simple that it will be easily understood and appreciated from the accompanying diagram of a complete installation for one of a group of wells.

Referring to the letters on Fig. 50, A indicates the well casing, B a rotary drill stem fitted with a bit C and a back pressure valve D, in the usual manner. Above these is screwed the sleeve valve E. This is shown in section in Fig. 51, and consists of a perforated casing forming part of the drill stem, with a movable sleeve inside, also perforated, and attached by a conical screw to the discharge pipe F.

When the discharge pipe is lifted by means of the screw lifting gear L, the sleeve is raised a distance governed by a pin working in the slot shown, the perforations in the casing and sleeve coincide, and the valve is open permitting the liquid to enter the discharge pipe. In the same way it is closed by lowering the discharge pipe. It will be readily appreciated, and it has been proved in practice, that there is little probability of such a form of valve becoming so clogged by sand, as to become unworkable. The discharge pipe F should be of drive pipe in which the ends of the

tubes butt so as to give a uniform bore, and must be of a size proportioned to the yield and conditions of the well.

The sizes used in oil wells vary from 2 in. to 4 in. diameter.

The 2 in. and 2½ in. sizes can be used in a 4 in. drill stem and a 6 in. casing. The quantity of liquid provided for should be that which the well will yield under constant pumping, but a given size of discharge pipe will not deliver the same quantity of liquid under

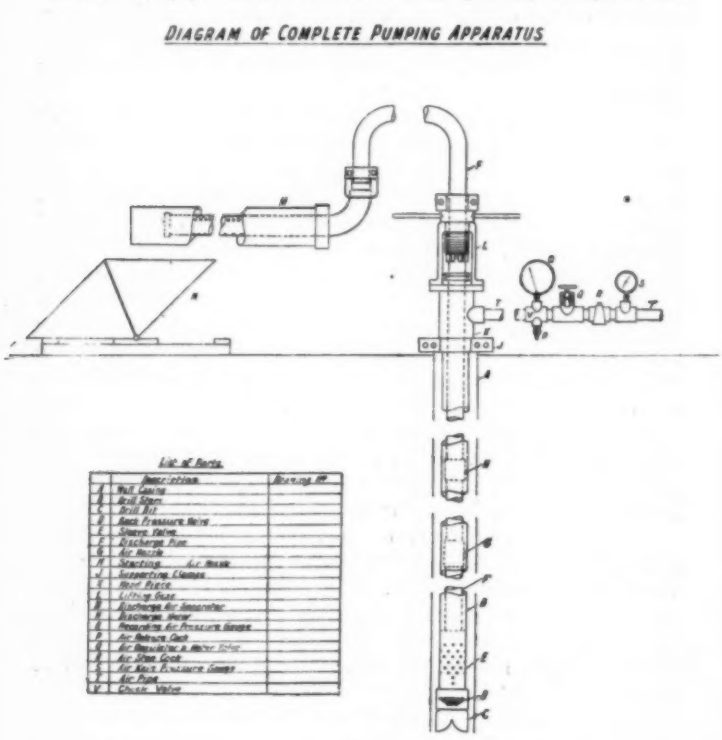

FIG. 50.

all conditions. The level of the liquid in the well, or the available air pressure, as compared with the height of the lift causes wide variations in the quantity of liquid obtainable with a given size. For instance, if the level of the liquid in a well 1,000 ft. deep stands 500 ft. from the surface, and the air pressure available be 220 lbs. per sq. in., the quantity of liquid delivered by a 2½ in. dia. discharge

pipe will be about 2,000 barrels per day, but, if the air pressure available be only 110 lbs. per sq. in., the quantity discharged will be about one half of this, or if the level of the liquid stands at 750 ft. from the surface only one third. The presence of gas with

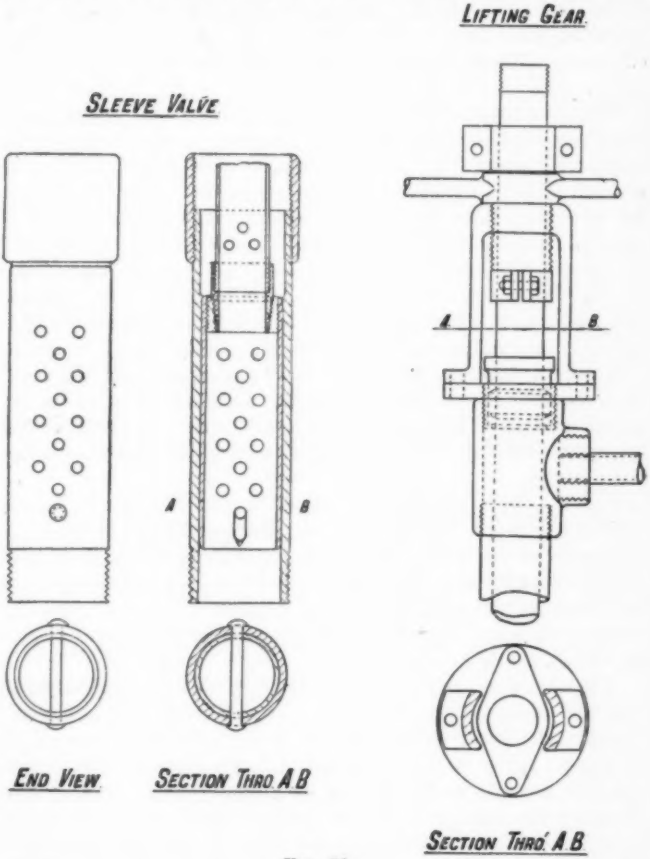

FIG. 51.

the oil will further reduce the quantity of liquid discharged, so that a still larger size of pipe may be required to obtain the possible yield. The form of the air nozzle will also seriously affect the capacity of a discharge pipe, and the full capacity cannot be expected unless the proper form of air nozzle is used.

The air nozzle G, shown in section in Fig. 52, is screwed in the discharge pipe at a depth below the surface of the liquid in the well depending on the lift, and the air pressure available. The area of the liquid inlet and mixing chamber above it must be proportioned, and varied, to meet the conditions of lift, air pressure, and gas in the oil. On the proper proportioning of these depends the efficiency of the air-lift, but the subject is beyond the scope of this paper.

When the standing level of the liquid in the well is much higher than the level maintained while pumping, a supplementary or starting air nozzle " H " must be used to avoid having to provide a much higher air pressure for starting the flow, than is required for pumping. This is of less importance when a single well is pumped and supplied by air from a separate air compressor, because the air pressure will fall automatically with the level of the liquid. When a group of wells is pumped from one air compressor the pressure in the air main must be maintained sufficiently high to restart any one of the wells of the group, and, if this pressure be much higher than the pressure required during pumping, there will be a useless expenditure of power in constantly maintaining the higher pressure. The starting nozzle enables this loss to be avoided by starting the flow with an air pressure not greater than the pumping pressure.

Fig. 58 shows the starting nozzle in section, and it will be seen that it merely provides a means of admitting air to the discharge pipe, and shutting the air off, no attempt being made to gain efficiency during the short period the liquid level is being lowered to bring the air nozzle into action. The air inlets are opened by turning the discharge pipe to the left, and, closed, when pumping is started, by turning to right.

The head piece K is screwed on the drill stem, and supported on the well casing by the clamps J. It contains a stuffing box and packing gland to prevent escape of air outside the discharge pipe, and has a flange, which supports the lifting gear L. The air connection is made at T, and the air passes by the annular space between the drill stem and the discharge pipe to the air nozzles. If a separate air compressor be used for the well only a recording pressure gauge is required by which to read the conditions in the well, the air supply being regulated by the working of the compressor. When a group of wells is pumped from one compressor the fittings shown in Fig. 50 are required. A check valve V, the recording pressure gauge O, and the air regulator and meter valve Q, are placed between the air stop cock R, and the well. A

AIR NOZZLE

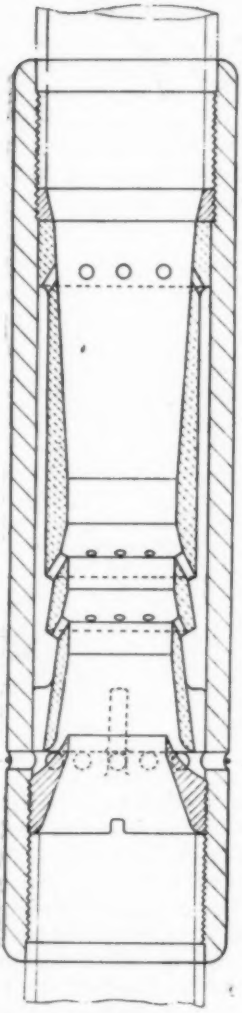

FIG. 52.

STARTING AIR NOZZLE.

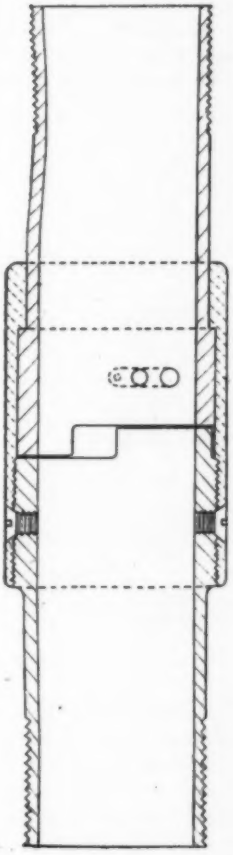

FIG. 53.

pressure gauge S is placed on the branch pipe from the air main. The air release cock P serves to release the air pressure from the well, when necessary. The air regulator and meter valve is shown in section in Fig. 54, and it will be seen that the construction is extremely simple. The supply of air can be regulated to a nicety by means of a cone on the spindle, while the degree of opening is indicated by the pointer on the scale. By noting the air pressures on the gauges, and the degrees indicated on the scale the quantity of air passing at any moment can be calculated by a very simple formula. The air consumption of the well can thus be checked, and com-

AIR REGULATOR VALVE - 1919 PATTERN.

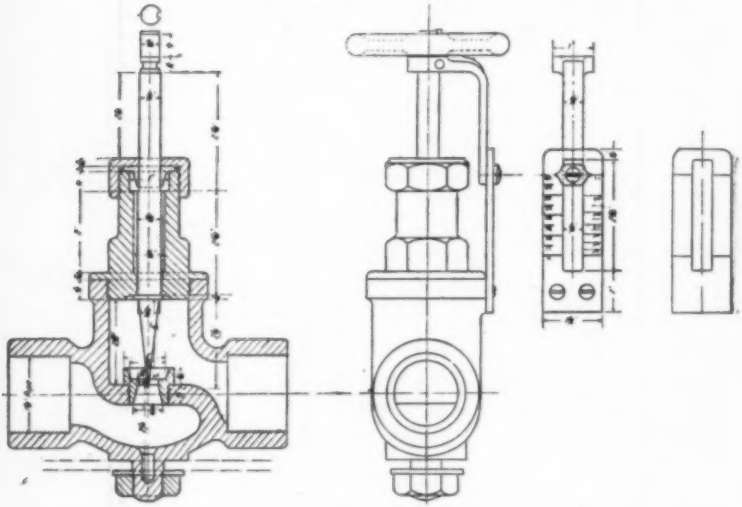

FIG. 54.

parison made with the consumption of other wells, taking into consideration the varying conditions of each, by which anything abnormal will be quickly detected. The discharge is led to the air separator M, which prevents the loss of oil in spray during the process of separation of the air from the liquid. It is designed so that the discharge can be observed, as it issues from the pipe.

The discharge pipe should be continued of uniform bore to this point, and directed vertically downwards. The discharge under these conditions gives the best indication as to when the proper quantity of air is being supplied. The discharge meter N is prefer-

ably of the tip type shown, and the most convenient size measures one barrel of liquid in either compartment. By fixing a stroke counter to the trunnion, recording the number of tips made, the number of barrels of liquid discharge is indicated. It is best placed lengthwise of the flow from the separator, and not across as shown in Fig. 50. The working of the apparatus may be briefly described as follows:—The drill stem being fitted with drilling bit, back pressure valve, and sleeve valve is lowered into the well, and if it be proposed to drill into the oil sand the rotary flush system must be used. Even to penetrate a sand cork in the casing the rotary provides the most satisfactory means, although it is by no means indispensable. Oil having been reached, either from having entered the oil sand or penetrated the sand cork, sufficient water or oil is pumped in to clear the drill stem of mud. The discharge pipe is then lowered with the air nozzle in the predetermined position, and screwed into the sleeve valve, and the air discharge connections made. If the rotary be not available to clear the sand cork, flexible hose connections must be provided for the air and discharge, allowing sufficient play to admit of lowering a length of drill stem. The connections having been made, air is supplied at a pressure to reach the air nozzle, the sleeve valve is lifted, and the discharge will be started, and continue while the supply of air is maintained. If oil has been reached it will be discharged with any sand it may carry, but if there be a sand cork in the casing to be penetrated this must be accomplished by raising and lowering the drill stem, at the same time rotating if necessary, while the discharge is maintained. When a length of drill stem has been lowered another must be added, and the operation repeated until the sand cork is pierced. If necessary sufficient liquid must be run into the casing to supply the discharge, and evacuate the loosened sand.

When the discharge has been started, the air regulator valve should be adjusted, until the discharge threatens to become intermittent. The quantity of air being supplied can be ascertained to check the working, and the air pressure indicated by the well gauge will show the head of the liquid in the well above the air nozzle, the position of which is known.

Before stopping pumping the sleeve valve should first be closed, and the air allowed to blow out the liquid in the discharge pipe, so as to avoid choking of the pipe by settling sand.

If it has been ascertained that the standing level of the liquid in the well is high above the pumping level, and a starting nozzle is used, the operation is the same, excepting that before applying

the air the starting nozzle should be opened, and closed when the steady discharge is established by air reaching the air nozzle.

In conclusion, some of the more obvious advantages of the system as applied to oil wells in general may be pointed out.

The wells may be in any relative positions to one another, so long as they can be reached by the air main or branches.

The economy of a central power station must be admitted, and air compressors are simple and durable machines. The power to drive them may be that available, steam, gas, oil, or electricity. When the conditions in each well have been ascertained, all the wells can be fitted to work at approximately equal air pressures. No other system is really simpler, or more efficient, or requiring less labour and supervision, only the supervision must be by technically trained oil engineers, because results do not depend merely on the working of the apparatus. The conditions of each individual well must be studied and defects in drilling, casing, and application of the apparatus remedied, and suitable modifications made if the best results are to be obtained, and the greatest possible production from each well. The air-lift pumping system makes this possible as no other pumping system does, and makes it profitable to allocate to the producing department of an oil field the best technical skill versed in all the processes of drilling and casing wells. The endeavour to obtain the greatest possible production from each well must involve a careful study of the most advantageous depth to drill into the oil sand and place the casing, the possibilities of production from the upper oil sands through perforations in the casing, and the exclusion of water from producing sands.

From these main considerations many others will arise: but, the importance of production must be recognised, when it is remembered that the cost of a well is practically the same whether it produce little or much, and that therefore every additional barrel of oil obtained is a direct gain. The actual cost of raising the oil being only a small proportion of the costs, the main consideration is to have a pumping system which has not the limitations of the present system, but will raise all the oil the well will yield, and keep the well clear, and in the best condition for yielding. These conditions are fulfilled by the air-lift system of pumping oil wells, with the apparatus described.

APPENDIX.

The following data indicate the results obtained by the Air-Lift System in Baku and in Trinidad :—

Baku.

Translated from the "Neftiannoie Dielo" (the official technical journal of Baku) of 5th June, 1908—

Number of Plot.	Number of Well.	Previous Condition.	Depth of Well. ft.	Lift. ft.	Oil per day by Baling. poods.	Oil per day by Air-lift. poods.	Remarks.
38 B E	6	Baled	1,985	853	500	1,500	Much water.
152 Sab.	30	„	1,311	1,100	4/500	2,000	Level of liquid low.
37 B E	74	„	1,813	603	800	15/18,000	Much gas, 8 in. casing damaged.
„	115	Abandoned	1,423	560/755	—	1/2,000	Fluctuated much water.
40 B	9	„	1,120	500	—	400	Water, with small percentage of oil.
„	12	„	1,155	433	100	400	„ „ „ „
Shon R	105	Baled	1,631	625	800	2,000	Very heavy oil formed emulsion.
42 B	77	Abandoned	1,236	615	—	300	Sand and water.
57 Sab.	43	Baled	1,519	960	2,000	2/3,000	Much sand.
4 B	14	Abandoned	1,101	405	—	700	Water and thick oil.
„	15	„	1,148	245	—	800	„ „
V group	14	Baled	1,400	490	2,000	3,000	„ „
23 B	65	Abandoned	1,575	755	—	1,500	Level of liquid fell from 420 ft.
Jul. R	176	Baled	1,402	455	700	8,000	
„	167	„	1,647	390	800	8/15,000	With packer flowed 15,000.
75 S	11	Abandoned	1,729	1,190	—	1,300	Much sand.
Shik. B	7	„	2,090	850	—	5,000	With packer.
„	4	„	2,044	940	—	5,000	„
Shon R	83	Baled	1,544	695	800	3/4,000	Thick oil.
Roths. B E	8	Abandoned	1,680	630	300	8,000	Damaged casing.

Trinidad.

Owing to changes in the engineering staff on the property on which the experiments have been carried out, it has been impossible to obtain the details for a table of results similar to that given for Baku wells. An air compressor of a capacity of 300 cub. ft. free air was installed in the spring of 1918. On account of the great difficulty in obtaining the necessary material, and the above changes, no complete experiment in controlling a well drilled into the high pressure sands has been carried out, but the air compressor has since been in constant use raising oil from an average of four wells with profitable results. These results have been obtained notwithstanding that incomplete apparatus not adapted to the conditions found in the wells have been used, and in most cases badly applied.

The first well in which the air-lift was installed had previously, and has since, yielded by pumping at the average rate of 180 barrels per day. By air-lift it yielded during 17 days at the average rate of over 500 barrels per day, when the apparatus was removed to another well from which a larger production was anticipated.

The second well had just been drilled into the oil sand, and was yielding about 500 barrels per day by periodical flows while cleaning by sand pump. By air-lift the well was cleared of sand, and during the first four days yielded at the rate of about 1,500 barrels of oil per day. This production gradually decreased until at the end of a week the pipes were withdrawn, and found to have been perforated as described in the paper (page 383).

A third well yielded by the air-lift at rates varying from 40 to 200 barrels per day with the piping about 200 ft. from the bottom. After the piping had been carried to the bottom of the well, thereby keeping the well clear of sand, the rate of production is reported to have increased to 400 barrels per day, although the rate was frequently reduced by inflows of sand, the foot valve having been omitted from the apparatus.

DISCUSSION.

The President said it was no light task to read a technical paper written by another man as impressively as if it were one's own composition, but he thought Mr. Howell had accomplished that feat, and that the thanks of the Institution were due to him as well as to the author for their joint production.

The resolution of thanks was carried by acclamation.

Mr. Beeby Thompson, in opening the discussion, said he had the pleasure of being in Baku when the author was carrying out many of his experiments, and he also spent a good deal of time in working at the air-lift problem which was then attracting notice. The author had referred to but few of the difficulties and troubles that were encountered in the early days when dealing with the difficult Baku conditions. At that time he thought the author was keen on developing a specialised process of air-lift by means of which the oil was more or less expelled from a displacement chamber. He had the pleasure of installing the first air-lift system in Baku, and it met with considerable success because it was put in a well specially suitable for the process. The well was of a small diameter, about 6 in., and deep with a high level of liquid, and it was necessary to bale with about a 4½-in. baler, which only allowed a very small production to be obtained. The quantity of water present was too large for such a small bailer to keep it down sufficiently to obtain any profitable production of oil. By inserting the air-lift they were able to get 2,500 poods (310 bls.) of oil per day, which clearly demonstrated the value of the process under special circumstances. He did not think, however, the process could ever be generally adopted for many reasons, a few of which he would explain. The necessity of removing deep water and also sand from the wells in the Baku oilfields was well known, as the oil was drawn from loose running sands, and there was nearly always some water present; but the introduction of air-lift brought about many strange and unexpected developments which at first presented difficulties to its widespread application. Very little was known of the process and its application to oil and no literature was available, so that when the system was first introduced those concerned had to study the subject for themselves. After the ejection of water from the bottom of the well oil entered the pipes, but there was an interval between the expulsion of water and that of oil when there was a mixture of the two often reaching proportions which encouraged the formation of emulsions. In some instances those emulsions were expelled in a solid form like butter or vaseline which gradually reverted to the liquid form on settlement. With changeable conditions of such nature, no general working formula could be of much use that would enable an engineer to calculate the quantity of air required to raise a certain quantity of liquid or the power required to do the work. It was found quite impossible to do more than approximately predict results in view of the constant fluctuations of level, water and oil proportions, inflows of sand, etc. It was likewise impossible to foretell when emulsions would be formed as their

formation was dependent upon such a variety of circumstances. If a well was working for a quarter of an hour on water, then for five or ten minutes on emulsion, and then for a quarter of an hour on pure oil, it was quite obvious that each of those conditions individually presented different problems which no one arrangement could adequately meet. With regard to the question of design, a straight pipe from the bottom to the surface was generally considered correct practice, but obviously it could not appear theoretically correct to have an increasing velocity in the rising main such as is automatically caused by the expansion of air under a gradually diminishing head as the surface is approached. The volume of air to liquid, which is the essence of the whole process, must have a constantly changing ratio from the bottom upwards, and to overcome this difficulty an English engineer developed the very ingenious idea of introducing a tapered rising main, starting with 3 in. or 2 in. at the bottom and at intervals increasing the diameter of the pipe as the surface was approached. Allowance was thus made for the expansion of the air, the same ratio of gas or air to liquid thus being approached. It was claimed that in working certain improved results were obtained, but those improvements were so small that the theory appeared to be in error somewhere. This idea is worthy of consideration, although the mechanical difficulties are very great in arranging for a tube which changed in diameter from the bottom to the top. Nearly all the waters in the Baku fields were highly charged with lime, in some cases they were very heavily charged. The aeration of the water possibly released carbon dioxide which had maintained the lime in solution, so that during ascent it was deposited on the tubes. Some rising main tubes were taken out from wells in which the diameter had been reduced from 2½ in. to 1 in., or less, and the material deposited on the tubes could not be removed. The incrustation was mainly lime of such consolidation that it could not be artificially reproduced.

Another point with regard to air-lift which in the future will restrict its use very considerably is the fact that the gas accompanying the oil is aerated. Everybody nowadays rightly considered economy and utilised the evolved gas to the greatest advantage; and whereas on a pumping well gas could be laid direct to the boilers or utilised in gas engines, the gaseous product from an air-lift could not be so used. The gas was also spoilt for gasolene extraction. One incident that came under his notice served to emphasise the great danger of efforts to utilise the gaseous product of air-lift plants. A friend of his showed him over his property on which he described

a most mysterious explosion which had wrecked part of the property. His friend told him that he had led the discharge from the air-lift into the oil tank from which a pipe was conducted to the boilers, but one day the boiler-house and tank were blown up. One can only wonder why for months such a plant had worked without accident, because the mixture created in an air-lift was a very explosive one. He supposed it so happened that on the occasion on which the explosion occurred the mixture had just reached the right proportions to produce a highly explosive mixture at the boiler track.

One other point about which very little indeed was known was the effect of air-lift on oils containing wax. His own impression was that the slight refrigerating effect to which the author referred, together with the possible liberation of the lighter gases, would cause deposition of paraffin wax. It was well known that in pumping wells in fields where much solid paraffins were present in the oil it was nearly always necessary to clean the wax from the tubes, and when an air-lift was used probably that state of affairs would be aggravated. His experience with air-lift, which he had also seen widely operated in California, was that it could only be economically used in very exceptional cases and in particular wells, and that it would never come into general use. With regard to the question of mechanical efficiency, if there were any compressor people present they would no doubt be able to state what the efficiency of a compressor was when it had suffered a little wear. He knew, from taking indicator diagrams, that the efficiency was perfectly appalling when a compressor got out of order, especially at the pressures which had to be used for deep wells, such as 200 to 250.

Perhaps one final difficulty should be referred to, namely, the fall of efficiency following a depression of level after installation. The author refers to one valuable addition to modern installations whereby the high initial pressure needed for starting can be avoided, but the loss of efficiency due to fall of level cannot be compensated for. When running under best conditions about 11 volumes of air per volume of liquid are used, but on a fall the ratio of air to liquid increases greatly and may exceed 40 to 1 with a submergence of 33 per cent.

The preliminary remarks of the author are particularly to the point, and should serve to dispel the many absurd arguments that were raised against the use of air-lift by those failing to appreciate its limitations or correctly interpret its results.

Mr. A. F. Dabell, referring to the statement made by the author that "the air-lift, properly applied, is the most advantageous

method of raising oil from wells yielding sufficient liquid for continuous working," pointed out that while the fields referred to yielded nearly 1,000,000 tons per month, the amount raised by the air-lift was in fact negligible.

With regard to the advantages of the air-lift for wells of small diameter, swabbing had to a great extent replaced that practice in Russia.

Mr. Cunningham Craig thought that Mr. Beeby Thompson had very clearly stated the general opinion that the air-lift system was not a method for universal application, but he gathered from the paper that every well must be studied as a special case, for the purpose of seeing whether the air-lift system could increase its capacity to the maximum. It was quite obvious that it was no use asking the ordinary driller to attempt to work such a complicated and scientific apparatus until he had studied it very carefully. The one great objection that he saw was the aeration of the gas to which Mr. Beeby Thompson had referred. If a well were gassing freely it seemed to him that very great danger might arise from the application of the system. He thought, however, the air-lift might prove very useful in wells that sanded up very badly, especially when they were first drilled in, as happened in very many wells in Trinidad. He had seen a well come in at about 1,600 ft., flow very violently, sand up for 200 or 300 ft., and never yield any oil again. It then used to be said that the oil sand had petered out, which of course was absurd. Attempts were made to clean out the well. One string of tools after another was lost in the hole and sanded up, with a baler on the top of them. One such well in Trinidad remained to the present day a monument—certainly not to the efficiency with which it was handled. All kinds of methods were tried to keep back the sand, such as perforated casing and screens. Those methods were persisted in for years, and on the whole he thought it might be said that they were fairly unsuccessful all through. Therefore, if the air-lift method applied at once, used with a rotary, had the effect of preventing sanding up when the oil was struck under very great pressure, he thought it might have very good effects in some parts of the Trinidad fields, for instance, where the oil sands were very thick and full of heavy oil under very great pressure. He understood that the author's work in Trinidad had, in some cases at any rate, been very successful indeed. There was one point, however, on which he did not quite agree with Mr. Stirling, namely, the objection to keeping a little pressure upon the sand. The only way in which it had been possible to produce some of the wells in Trinidad was

by throttling them down so hard that there was always a pretty big back pressure on the sand. The best well in Trinidad is that which he believed had yielded the most oil of the best quality, after yielding 60,000 or 70,000 barrels initial flow got blocked and sanded up about 400 ft. No attempt was made to clean it out for some months, but after it was cleaned out again and had yielded about 100,000 barrels in 58 hours it was sanded up a second time. The well never produced properly until it was throttled down to a ½ in. pipe. During the time it continued to flow—and he believed it was still flowing after six years—he had month by month the accounts of the production of the oil from the ½ in. pipe, which must have kept a very big pressure upon the sand. No doubt it did sand up a good deal, but never so much that it had to be cleaned out again with resultant violent flow. He therefore thought that putting back pressure on the sand in a well of that nature which was apt to get loose was often a very good thing. He was very sorry the author was not present to give some instances in regard to particular wells which were known to some of the members, and he hoped that the author would do so when he made his written reply to the discussion. He agreed with the previous speakers that to say that the air-lift method could be applied universally was rather a larger claim than he would like to endorse.

Mr. W. J. A. Butterfield said that speaking as one without any experience of air-lift pumping of oil, it seemed to him, after listening to the discussion, that some of the objections raised to the system were entirely due to the use of air, and that compressed gas in place of air would overcome some, at any rate, of them. It should be possible to work in a closed circuit by letting the discharge of oil come into a chamber closed with a small liquid seal; then compress the gas collecting in the chamber from the well, and return that for the lift pumping. That, at any rate, would overcome the dangers due to the mixing of air with gas, and also the loss of gasolene. Only the surplus gas from the chamber would be liberated for use as fuel, etc. He did not know whether that was a feasible scheme, but it seemed to him that some of the objections raised were not due to the use of compressed gas for lifting, but to the gas hitherto used having been air. He was not sure how that would affect the difficulty of the deposition of chalk from water, but it might be found that even that would be overcome, because the liberated carbonic acid, if that was responsible, would also be returned in the closed circuit with the compressed gas.

Dr. Henderson said he had no experience of air-lifting applied to oil, but he had in regard to raising water containing a large

quantity of sediment, although only for short lifts. The proof of the pudding lay in the eating, and if the author could demonstrate the success of his claims in regard to any particular field he was sure that no body of people would be more pleased to adopt the method than the members of the Institution. Those members who were dealing with certain difficult production problems were eagerly watching the development and hoped it would be a great success, although many of the objections which had been raised in the course of the discussion had naturally been brought home to those who had already studied the question theoretically.

Mr. F. C. Paget said it was rather difficult to follow the paper without the diagrams. For instance, he was not sure if the author used a separate oil pipe or whether the drive or the rotary tool was used as the air main, the oil pipe being outside. Perhaps the diagrams would explain that point. The author had not dealt at all with the question of developing oil fields by means of compressed air, a subject which he believed had been taken up on some of the oil fields at the present moment. By applying pressure to the formation in connection with developing water supplies in this country, he believed considerably increased quantities had been obtained. The author had referred to different air pressures giving different results. His own experience of an air-lift system was that the pressure was always governed by the submergence. He could not follow therefore why with a certain pressure more oil was obtained than with a lower pressure, if the submergence was the governing point, unless the air outlet was so restricted that an unnecessary pressure of air was required to get the desired quantity of air into the water pipe.

With regard to the question of different sized pipes, it had been known for many years that as the air decreased in pressure the volume naturally got larger, but at the same time the amount of liquid, whether oil or water, fell off considerably. For instance, in lifting 1,000 ft. the pipes might pass 10,000, but in lifting 2,000 ft. the volume at the top might be 5,000. Therefore the one counteracted the other very considerably. He thought it was admitted that an air-lift was not the most efficient type of plant, but on oil fields, where power ought to be very cheap, the small efficiency of an air-lift pump should be no governing factor in its adoption.

Further it is surprising to note that no tests seem to have been carried out on wells which were only slightly overflowing. The speaker knew of innumerable cases where considerably greater outputs can be obtained by slightly diminishing the head, and it

is in cases of this description where air-lifts in oil fields would double, treble, or quadruple outputs at very small cost.

The air-lift pump has been specialised in by several engineers, who have spent a considerable number of years in bringing it to its present state of efficiency, and it is remarkable that none of the oil Companies appear to have approached those firms to deal with and assist them with the problem of augmenting the oil flows. It should be quite unnecessary at the present day for the oil Companies to start experimenting themselves when the necessary data has already been accumulated.

Mr. Howell said he desired to add one or two remarks not of a scientific character but from the practical side. The air-lift system, so far as he could ascertain, had only reached its experimental stage of construction, but the author had put down in graphic figures some of the actual results, which had been obtained by using the system from damaged wells and wells which might otherwise have been abandoned. He understood that the apparatus used in Baku was put together, not constructed, by a firm which collected the various parts from difierent manufacturers; this was a most unsatisfactory method, and did not exploit fairly the value of the system. The author admitted that, unless there was a technical engineer on the spot, it might be most dangerous to employ the air-lifting system in a well under those conditions. On the other hand, experience showed that the system intelligently applied did not damage a good well. He did not think for a moment that Mr. Stirling really intended to suggest that the air-lifting system could be applied to all kinds of wells, because he distinctly stated in his paper that a scientific study ought to be made of a well before the air-lift system was applied to it. If the air-lift system was going to be used for the purpose of increasing the oil flow, particularly from those wells which were more or less damaged and possibly had ceased to flow, he thought it would be a pity if any discussion that occurred on the subject in any way damped the ardour of those who desired to try a method which at the present time had only reached its experimental stage and had not been scientifically and accurately worked out in its final stage of a completed apparatus. He understood that the author had fixed two nozzles for the purpose, *inter alia*, of overcoming the extreme high pressure which might otherwise be required to cause the in-flow not only of oil but of gas, water, or even sand, because a certain suction was set up at the bottom of the tube; the extra nozzle is termed the "starting nozzle," and it performs a two-fold function. If the sand were flowing, trouble would of course ensue, but, if baling or pumping

were being carried out in a case where the sand was flowing, would not the trouble be equally as great as if the air-lift system was adopted? Whether the ordinary mechanical slow process of baling, pumping, or other system were adopted, difficulties still had to be contended with, and as the author's air-lift system was the most effective way of removing sand, which was in most of the wells of which they had experience without suspending actual workings, a very important economic fact, he thought it should receive a trial. In many cases there was a flow of sand at such a high velocity that it would blow the bottom out of the well as well as causing other serious, almost, irreparable damage. Under the conditions and advantages expressed by Mr. Stirling in his paper he thought the system should be given a fair trial.

In conclusion, Mr. Stirling warns us against unsuitable designs which are often put on the market, owing to the apparent simplicity and ease of demonstration of the air-lift principle. In a small hand-book, No. 76, issued by the Ingersoll-Rand Company, some useful information is given, which might be of use when studying the system.

The meeting then terminated.

The **Author,** in a written communication, states that it was a great disappointment to him that he was unable to be present to read his paper, and to reply to the points raised during the discussion. He desires to thank the President and members present for their kind appreciation, and the members, who under the somewhat discouraging circumstance of the author's absence, showed sufficient interest in the subject to contribute to the discussion. Also to thank Mr. Howell for undertaking the somewhat onerous duty of reading the paper, and for the keen personal interest he took in the subject, as evidenced by the apt remarks he made at the close of the discussion.

In reply to the interesting points raised by Mr. Beeby Thompson, the author admits that he has referred to few of the difficulties and troubles encountered in the early days in Baku, because now they are for the most part understood, and have been or can be overcome. The experiments with the displacement system, to which he refers as carried out by the author, proved that the efficiency obtainable was much lower than could be obtained under similar circumstances by the air-lift, as even then developed, and the apparatus was much less simple. With regard to the difficulties described when water is present with the oil, these only arise when the water and oil come from different sources, and the difficulty can be overcome by the proper use of packers as described by the author (page 382). The

difficulty with very heavy oil forming an emulsion only occurs with certain proportions of water, and a remedy has been indicated (page 382).

The danger referred to, of using the mixture of air and gas for boilers and gas engines, can be guarded against by interposing wire gauze screens in the gas mains, as is common practice where mixtures of air and gas from furnaces are used as fuel. The extraction of gasolene from the gas would probably only entail the handling of a larger volume, which moreover would be only slightly larger, because the additional air required in such case to raise the oil would be small. In the case of difficulty with paraffin wax alluded to, this could probably be overcome by heating the air before it entered the well. The mechanical efficiency of an air compressor can be more easily maintained, than that of a deep well pump. Air-lift apparatus can now be designed to give as high efficiency with a very low ratio of dip to lift, as formerly could only be obtained when a dip equal to the lift was available, and much lower air pressures can consequently be used. By using a suitably proportioned apparatus the fall in level can be met, and the efficiency of the process maintained. With a suitably designed air-lift apparatus 11 volumes of free air should lift 1 cub. ft. of liquid 1,000 ft. with a ratio of dip to lift of 1 to 1, or 50%, and with a ratio of 1 to 2 or 33% only 15 volumes should be required, the power used being almost equal, but the apparatus would be differently proportioned in each case. Apart altogether from the proper design of the apparatus, the air-lift has the disadvantage in careless hands that air, and consequently power, can be so easily wasted.

The author has before him a return giving details of a 15 days' trial of an air-lift apparatus, during which the level of the liquid varied very little, and yet each day shows variations in the volume of air used, per volume of liquid raised, of from 22 to 80 volumes. Had the apparatus been properly designed to suit the conditions only 14 volumes would have been required, but 22 volumes were required to do the work owing to unsuitable design, and on some days the difference between that and 80 volumes was absolutely wasted. In reply to Mr. A. F. Dabell, the author admits that the statements must appear rather startling, but can see no reason, even after further careful consideration, to modify the second paragraph of his paper. He would merely draw attention to the condition that the air-lift be "properly applied," and that the wells yield "sufficient liquid for the continuous working of an apparatus of the smallest practicable size." During 1903 a careful estimate gave over 60,000 tons per month as the production of oil by air-lift

in Baku, and why it should be now "negligible" the author can only surmise.

In reply to Mr. Cunningham Craig the author agrees that it is often necessary, when high pressures are encountered, to restrict the flow, and thereby maintain a back-pressure on the oil sand. When this is not sufficiently accomplished by the restricted discharge pipe in the apparatus described, further restriction can be applied to the discharge. Only when the pressure falls is it advantageous to reduce the pressure on the oil sand by lowering the level of the column, so as to induce a greater yield of oil. Just as in a gas well with high pressure, the outflow is restricted to give the quantity required, but when the pressure falls a vacuum pump is applied to induce a greater yield of gas.

The drawback to throttling the discharge of an oil well at the top, when large quantities of sand are present, is that the velocity of the flow in the casing of large diameter is reduced so that the sand is not carried up, but settles in the lower part of the casing, and may eventually stop the flow. The casing head must then be opened up and the sand cleared by sand pump, incurring the danger of an uncontrollable flow. With the apparatus described the flow is controlled by the valve at the bottom of the well, until a discharge pipe of suitable size is inserted, so that, when the desired flow is permitted, the velocity in the pipe will be sufficient to carry up the sand, and so keep the pipe clear to the bottom.

The application of the air is only as an auxiliary, in case the pressure should fall, or the gas be insufficient to maintain a flow. Experiment is required to evolve the most suitable supplementary devices to use with the apparatus, and to acquire practice in their use, but unfortunately the only experiment attempted was stopped at the start by the lower part of the rotary drill stem becoming choked by debris, which would not pass the rotary back pressure valve. The sleeve valve of the apparatus was consequently also choked, through the defect in the rotary, which could have been avoided by proper screening of the flushing liquid. The interesting particulars, which Mr. Cunningham Craig gives of experiences with wells in Trinidad, explain in great measure why the development of such a rich oilfield has been so retarded, and the failure of so many of the pioneer companies. It is curious to contemplate that the solution of most of these difficulties was publicly demonstrated years ago in Baku, and that the attention of several of those engaged in the technical work on the Trinidad oilfields was directed to the published facts, at various times during the past 10 years. The exceptional case where the mere restriction of the discharge was

sufficient to secure a satisfactory production, only proves that more is required when loose sand is present, although in wells free from sand, such as those which are worked in Mexico, nothing more is necessary. Records from properties in other loose sand fields indicate that only occasional wells, in which other conditions are favourable, yield to the simple restriction of the discharge. The author does not claim that the air-lift method can be advantageously used universally, because he specifically excepts wells yielding small production.

Replying to Mr. W. J. A. Butterfield, the author knows of no reason why gas should not be compressed and used in place of air, if the advantages so obtained would compensate for the necessary additional plant.

Replying to Dr. J. A. Leo. Henderson, the author relies in the records published in Baku to prove the successful demonstration of many of his claims in that field, and it must rest with those interested to take advantage of the experience gained for other fields, and to carry out the necessary experiments to prove the other claims, which, if successful, would be of undeniable advantage in several known fields.

The author is, and has always been ready, as far as his other engagements permit, to assist and give the benefit of his experience to anyone prepared to seriously test the method.

In replying to Mr. F. C. Paget, the author observes that the submergence or dip absolutely governs the air pressure, and it is an axiom in designing air-lift apparatus that the air outlet should be unrestricted. Assuming an adequate supply of air, the volume of the liquid discharge is governed by the area of the discharge pipe, and the ratio of the dip to the lift. The dip used may be governed by the available air pressure, or by the depth of liquid in the well. The air-lift plant as generally installed is a very inefficient type of pump, although a comparatively few examples are recorded of reasonably high efficiency, approaching the theoretical attainable, having been obtained. It must be borne in mind that the average efficiency of the deep well pump used in oil wells is low, and can generally be surpassed by a well designed air-lift pump. A few years ago the author had the pleasure of meeting an engineer, who had been engaged during many years in designing and installing air-lift plants. He had obtained exceptionally high efficiency in one well, but confessed that he had never been able to attain equal efficiency in any other well. He had used exactly similar apparatus in other wells, but the conditions were different, and similar results were not obtained. The fact is that he had stumbled on the pro-

portions in the apparatus, which gave the better results, but did not understand in what they consisted, and scoffed at the author's explanation because it ran counter to all published literature on the subject, yet the matter was obvious.

The air-lift apparatus requires no experimenting with, but each well must be experimented on to discover the conditions, and only the staff on the oil fields can do this.

The production of a well slightly flowing can be increased by the application of compressed air with the crudest appliances, but to do so efficiently requires a suitably designed apparatus.

The author desires to compliment Mr. Howell on his apt remarks, and to emphasize the point that the men in charge of the air-lift system of pumping must have a scientific as well as a practical education. The working of the apparatus is based on scientific principles, and the various happenings during its operation can only be properly analysed and interpreted if these principles are thoroughly understood. One of the most glaring causes of want of progress in oilfield methods is the lack of ability to analyse the relations between cause and effect. The Ingersoll-Rand air-lift apparatus referred to is probably as efficient as any other on the market, for more or less standard conditions; but nevertheless is inefficient, and lacks the means of adjustment to meet the varying conditions, which have to be dealt with in oil wells.

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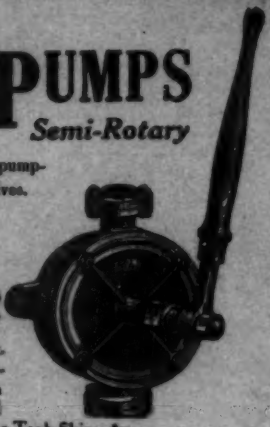

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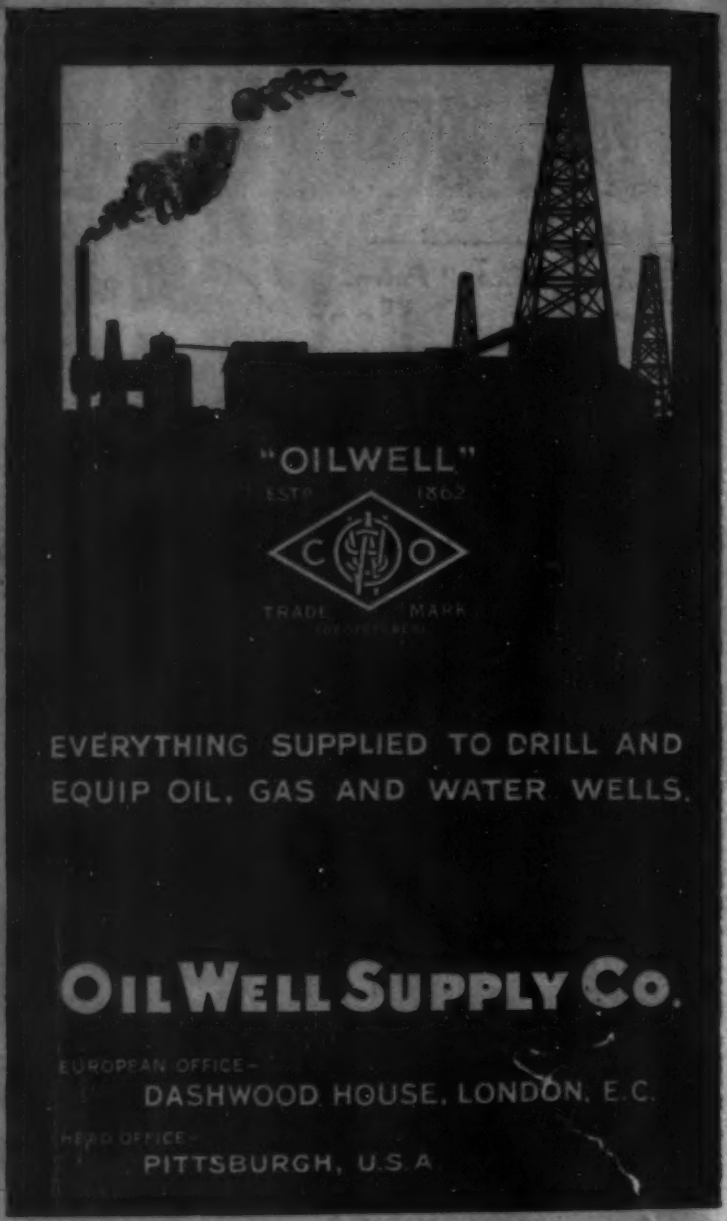

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